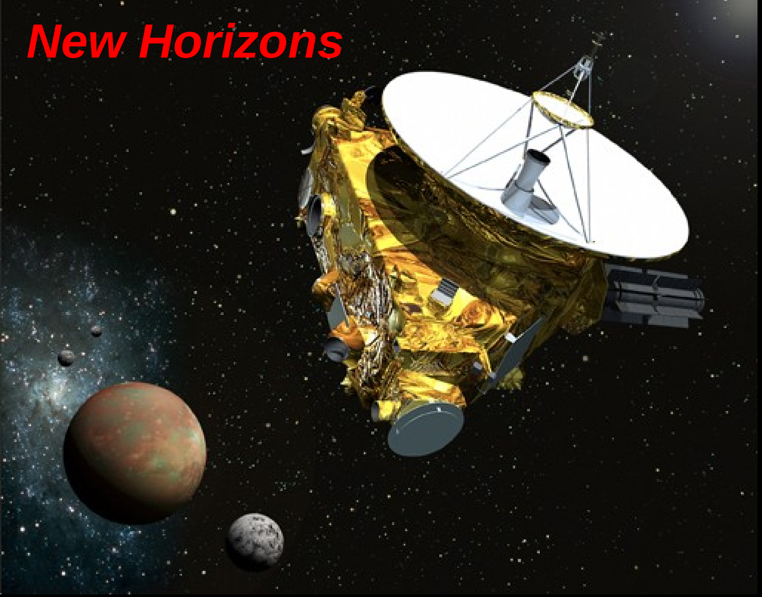
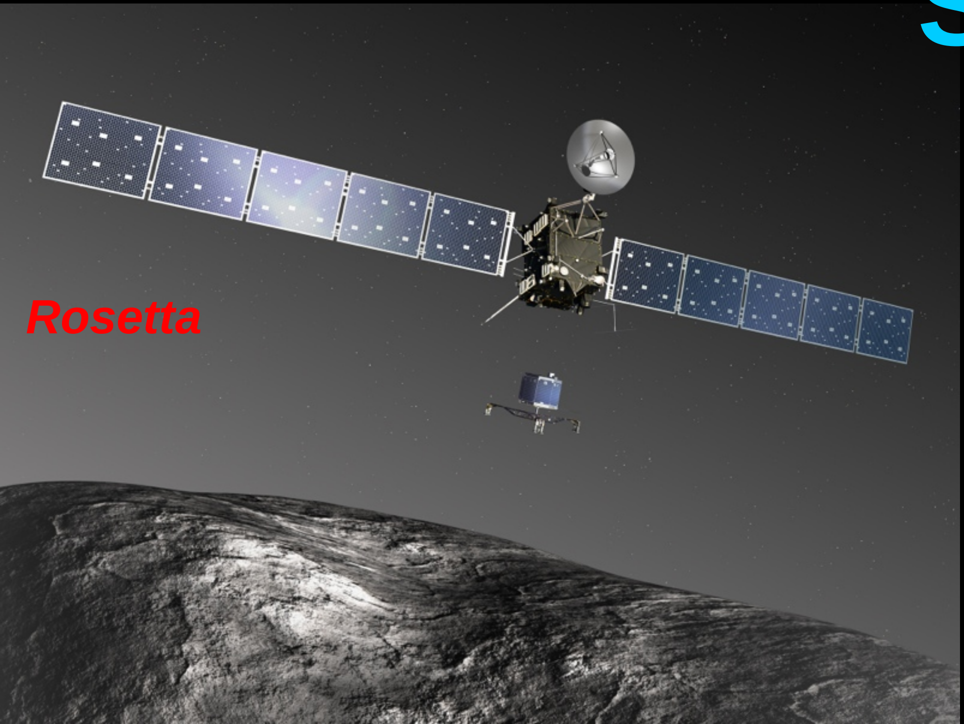


Exploring the Solar System's Third Zone



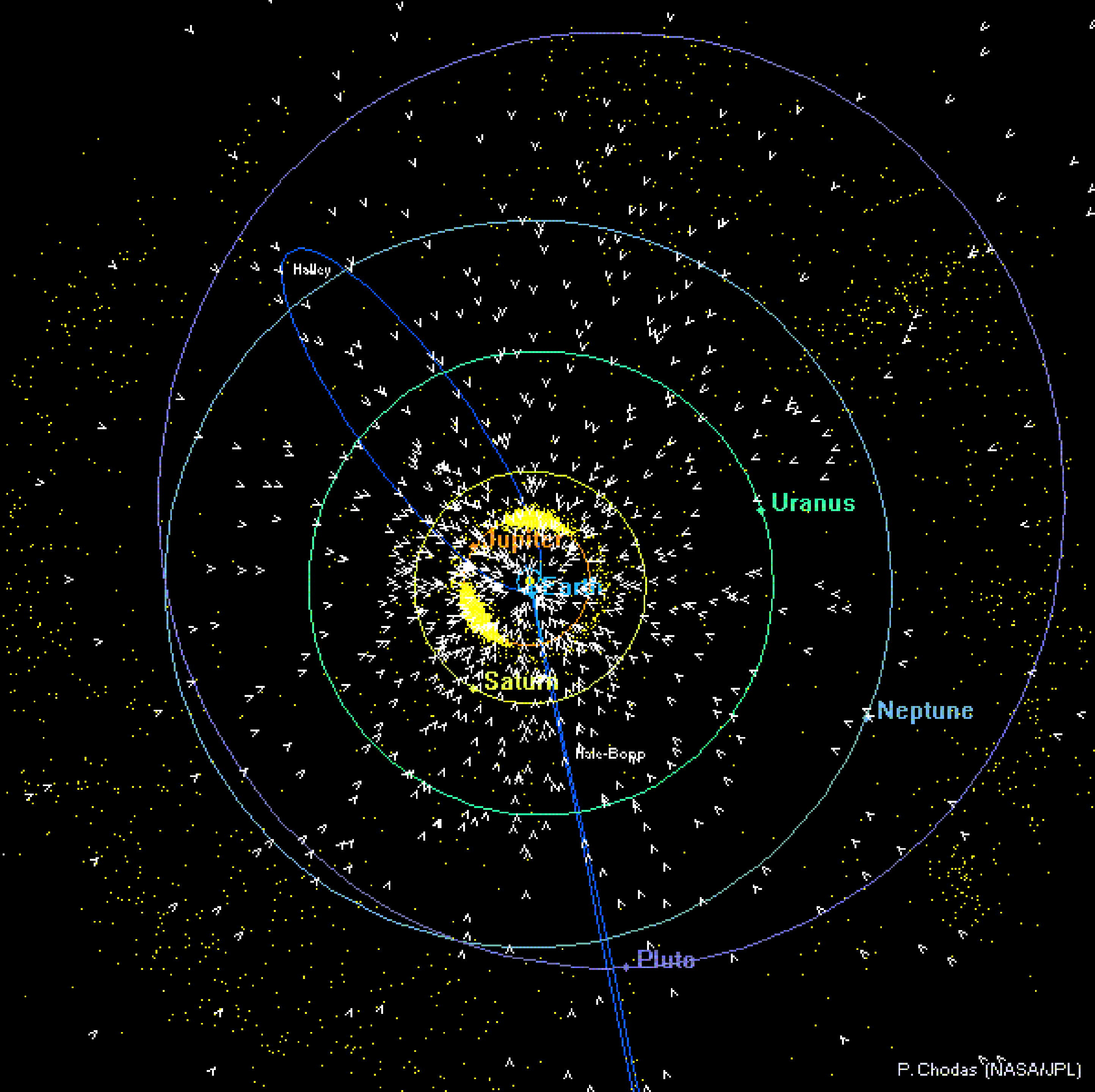
Hal Weaver (JHU/APL)
New Horizons Project Scientist
Rosetta-Alice Co-Investigator

Frontier of Planetary Science

Explore a whole new region of the Solar System we didn’t even know existed until the 1990s

Pluto is no longer an outlier! It is the most accessible member of *large* KBOs, and *New Horizons* provides the first close-up view

Rosetta is providing the most detailed view yet of the “scattered” KBO population

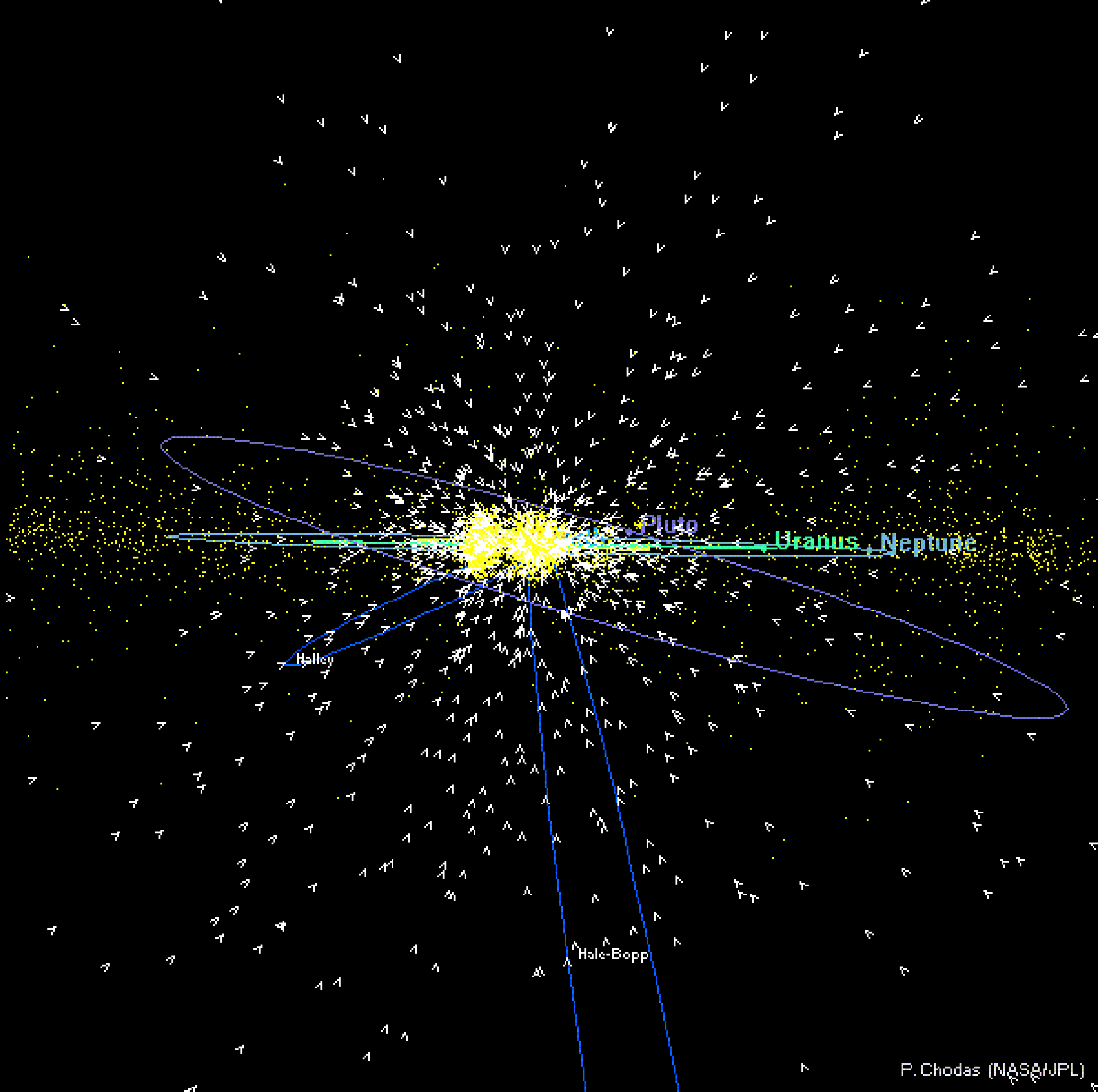


Edge-On View

The orbits of the KBOs are very different from those of the “major” planets, which lie in the *ecliptic plane*

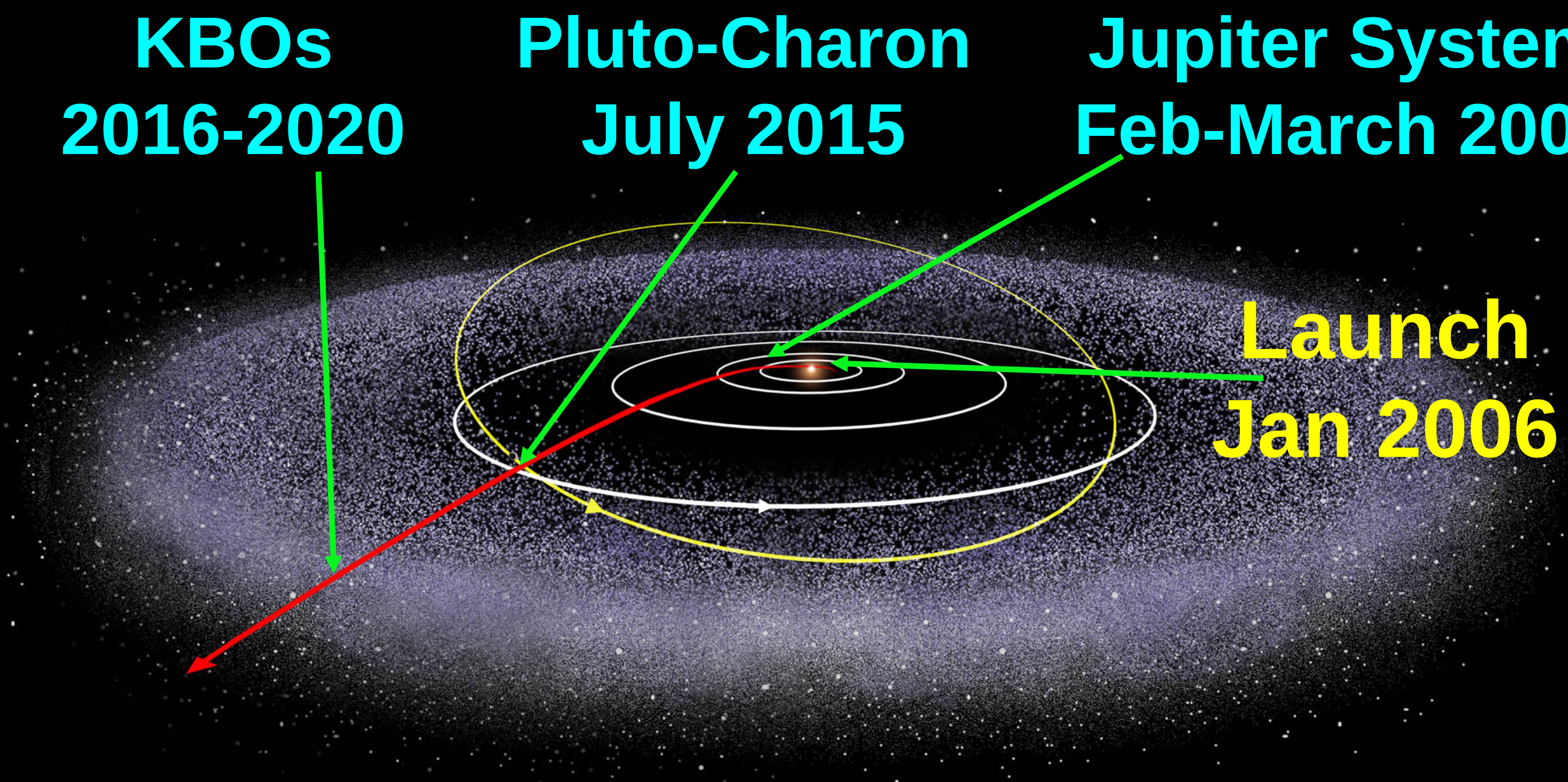
KBO orbits are more inclined and more elongated

The discovery of different *dynamical families* of KBOs has motivated new modeling of the Solar System’s origin and evolution: *Need massive radial migrations of the Giant Planets*



New Horizons: To Pluto and Beyond

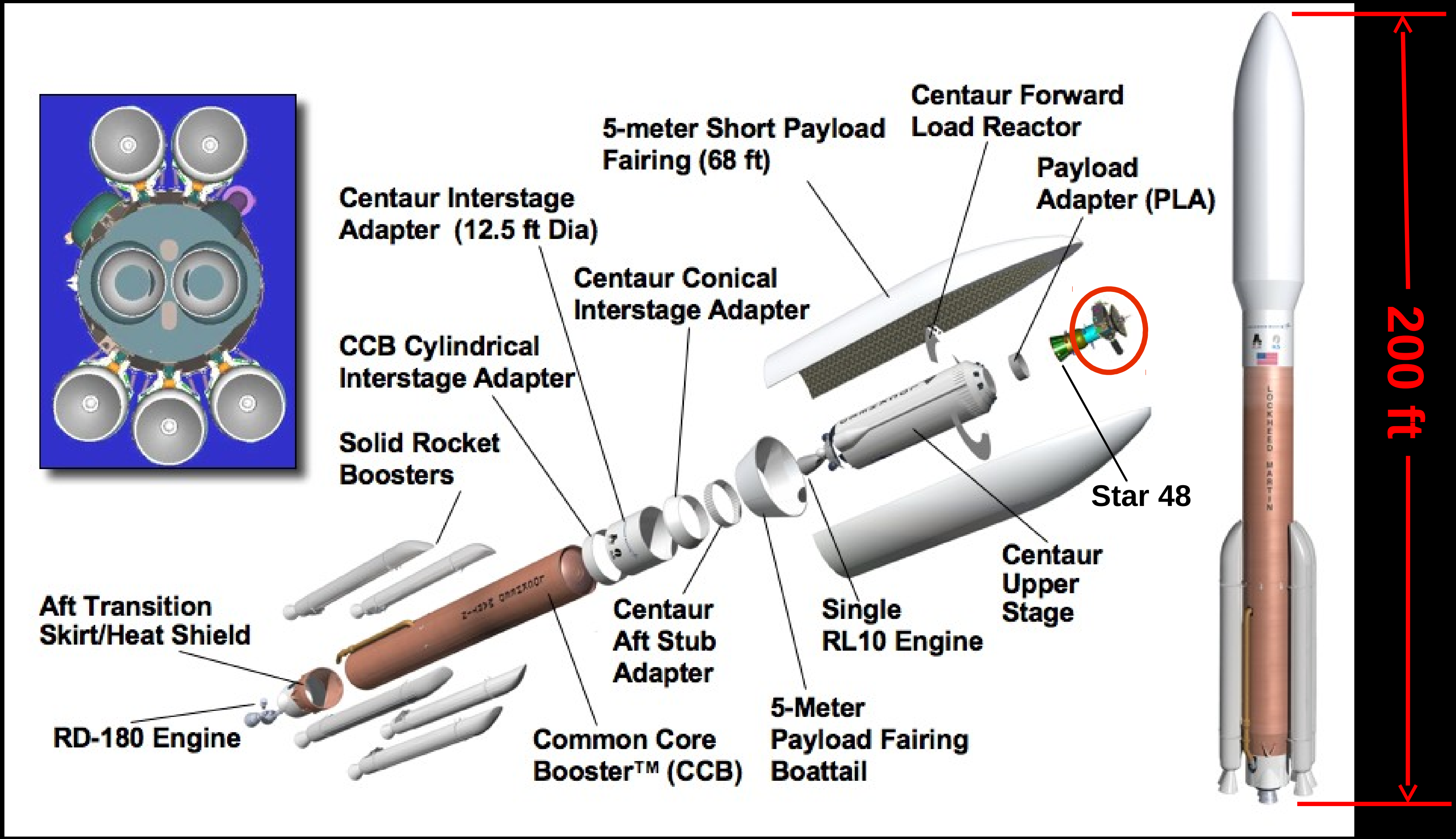
The Initial Reconnaissance of The Solar System's "Third Zone"



PI: Alan Stern (SwRI) ***PM: JHU Applied Physics Lab***

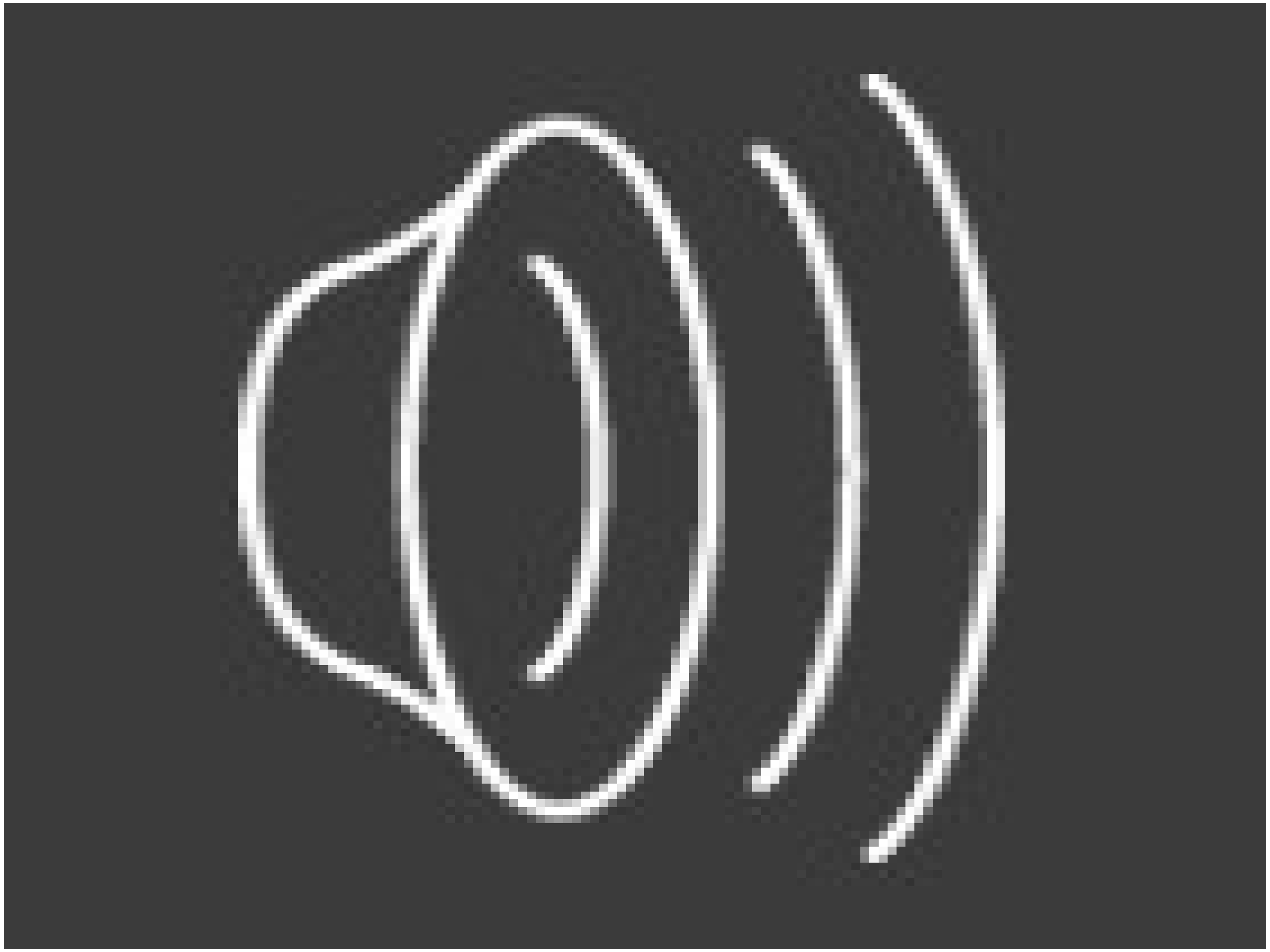
New Horizons is NASA's first New Frontiers Mission

Getting to Pluto Requires a LOT of Energy

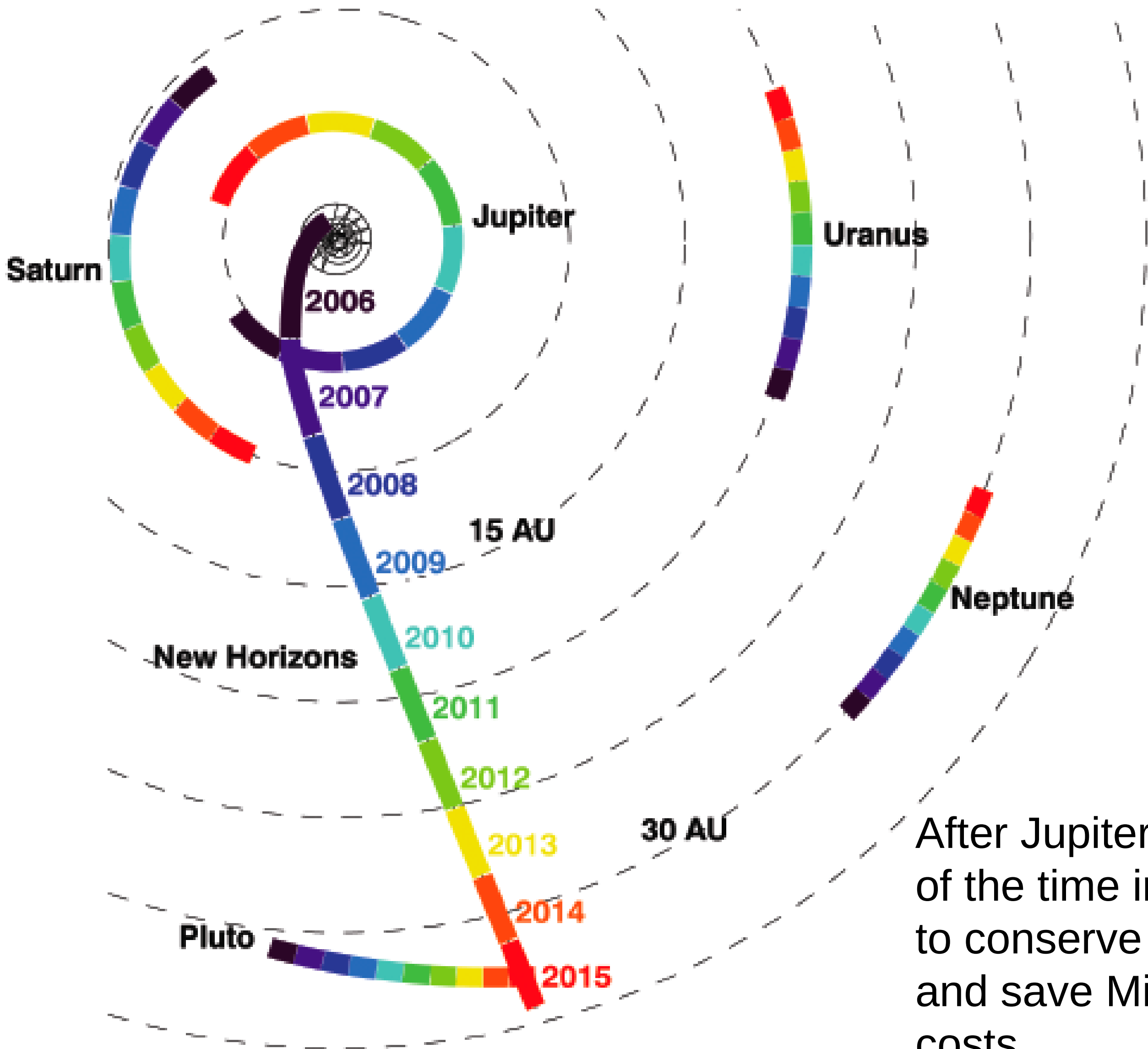


NH Launch Vehicle : Atlas V 551

Launched on January 19, 2006

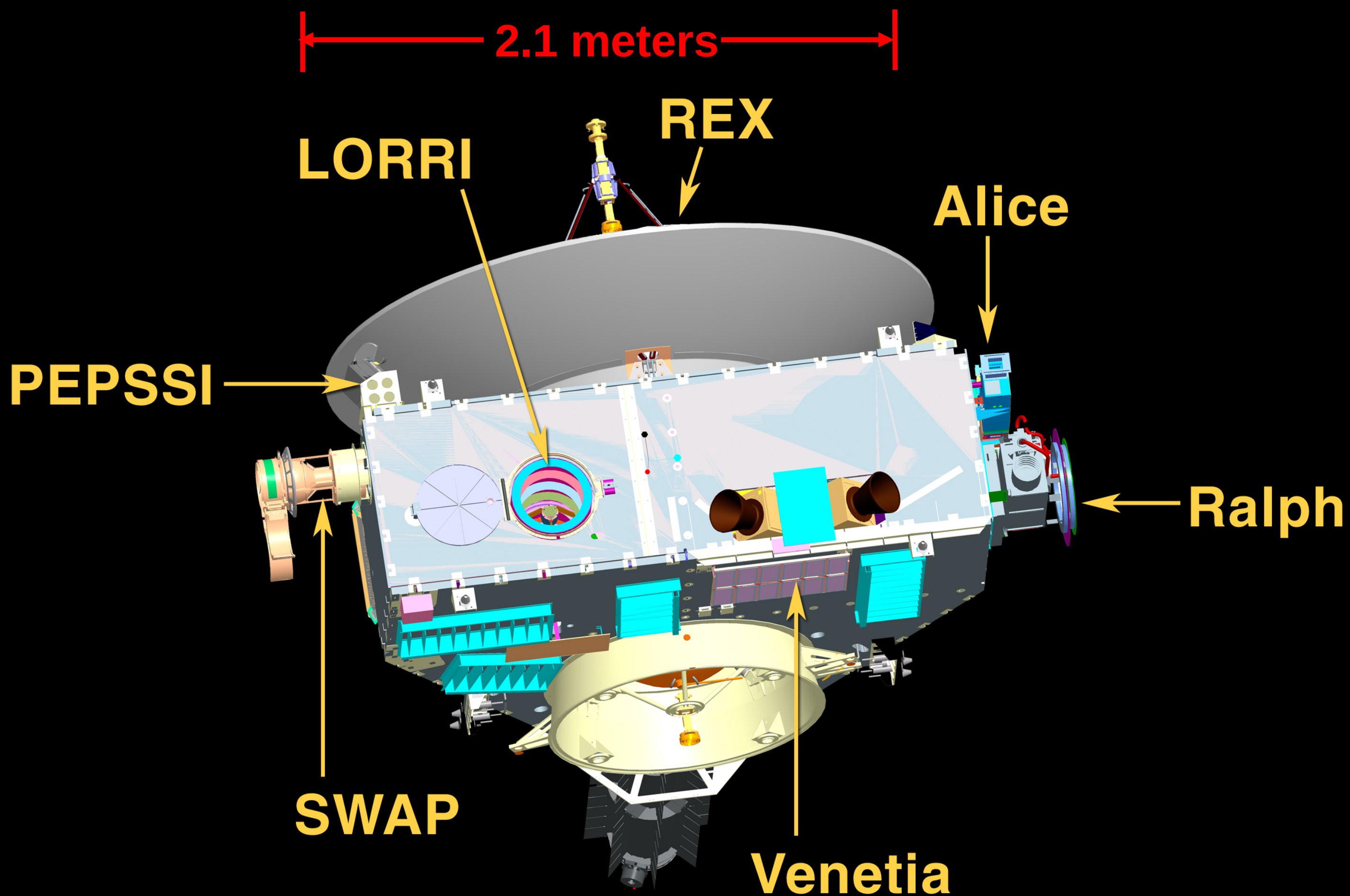


New Horizons Year-by-Year



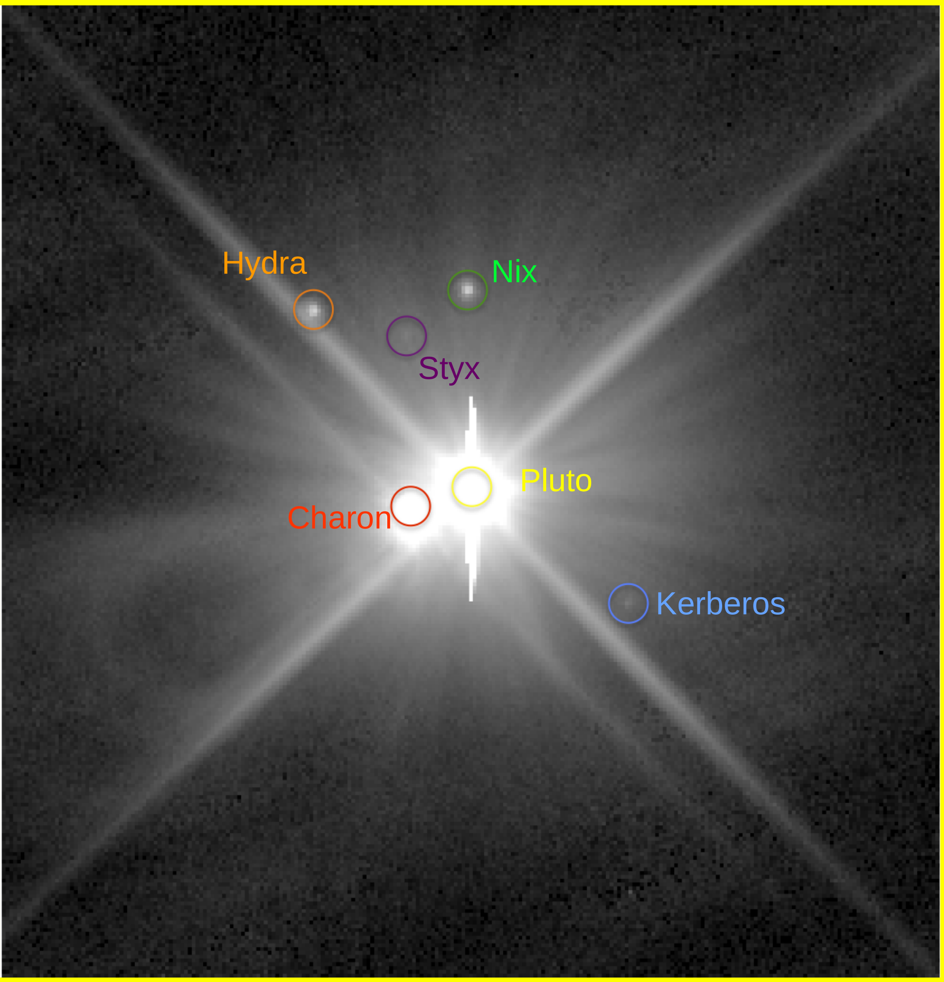
After Jupiter, spend most of the time in hibernation to conserve subsystems and save Mission Ops costs.

Spacecraft & Instruments

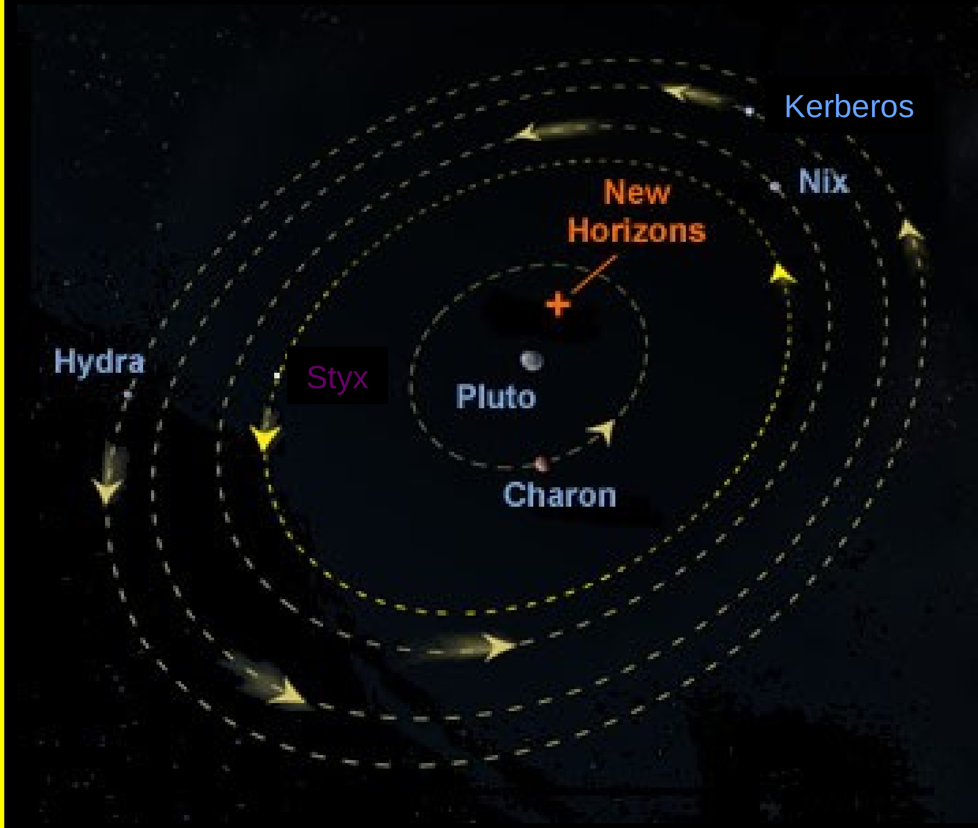


All together, these instruments draw < 30 W and weigh < 70 lbs

The Pluto System : *Six* Objects



V ≈ 23.0, 23.5, 26.5, 27.0 for Hydra, Nix, Kerberos, and Styx



Left **: Composite Hubble WFC3 image (102 min total exposure time) showing the complex Pluto satellite system. Styx is ~150,000 times fainter than Pluto. *Right* : Cartoon showing satellite orbits, whose periods are *approximately* 1:3:4:5:6 (Charon:Styx:Nix:Kerberos:Hydra).**

NH Principal Science Objectives

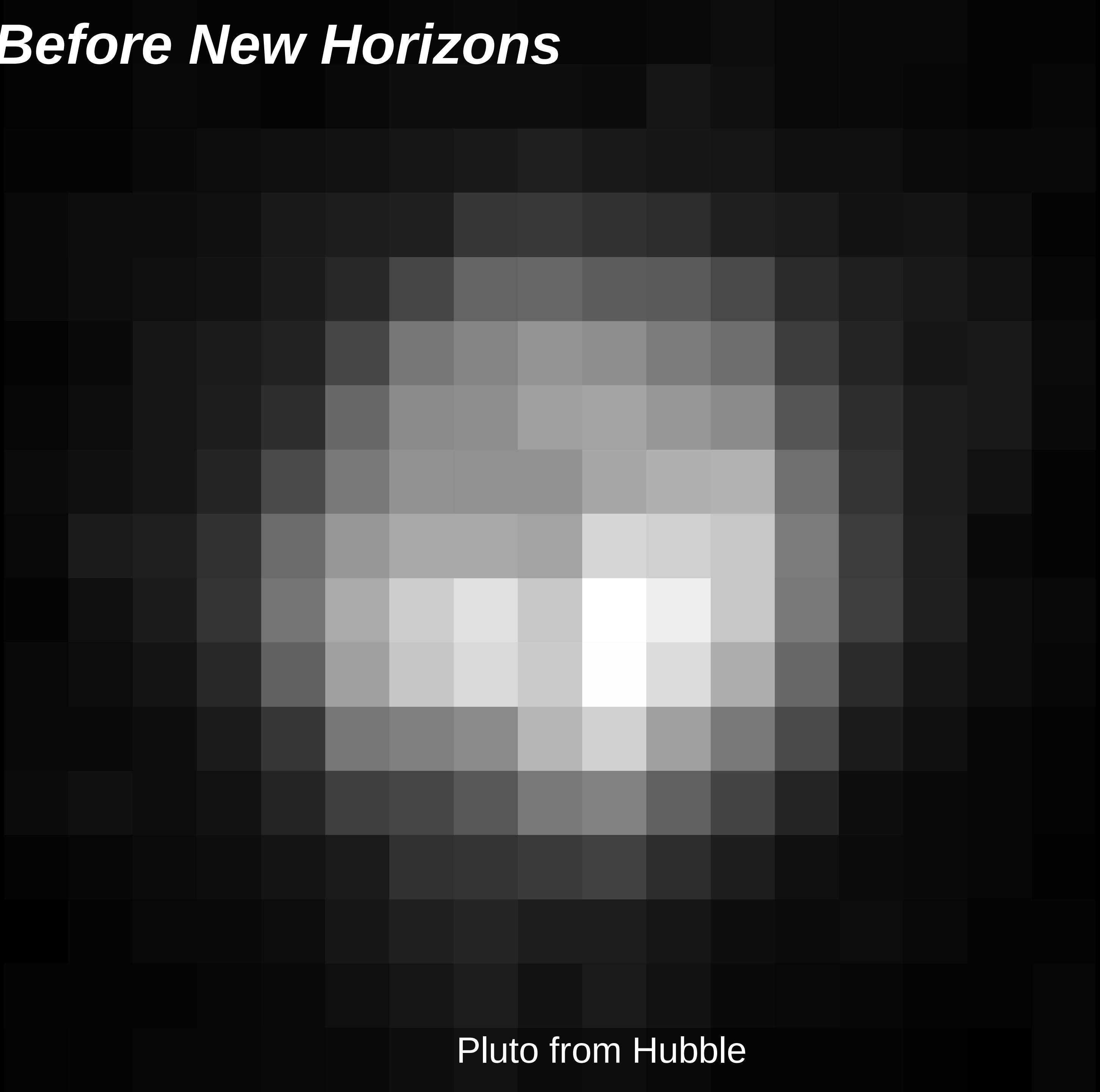
1. Characterize the global geology of Pluto and Charon

2. Map the surface composition of Pluto and Charon

3. Characterize Pluto's atmosphere and its escape rate

Imaging Results

Pluto Before New Horizons



Pluto from Hubble

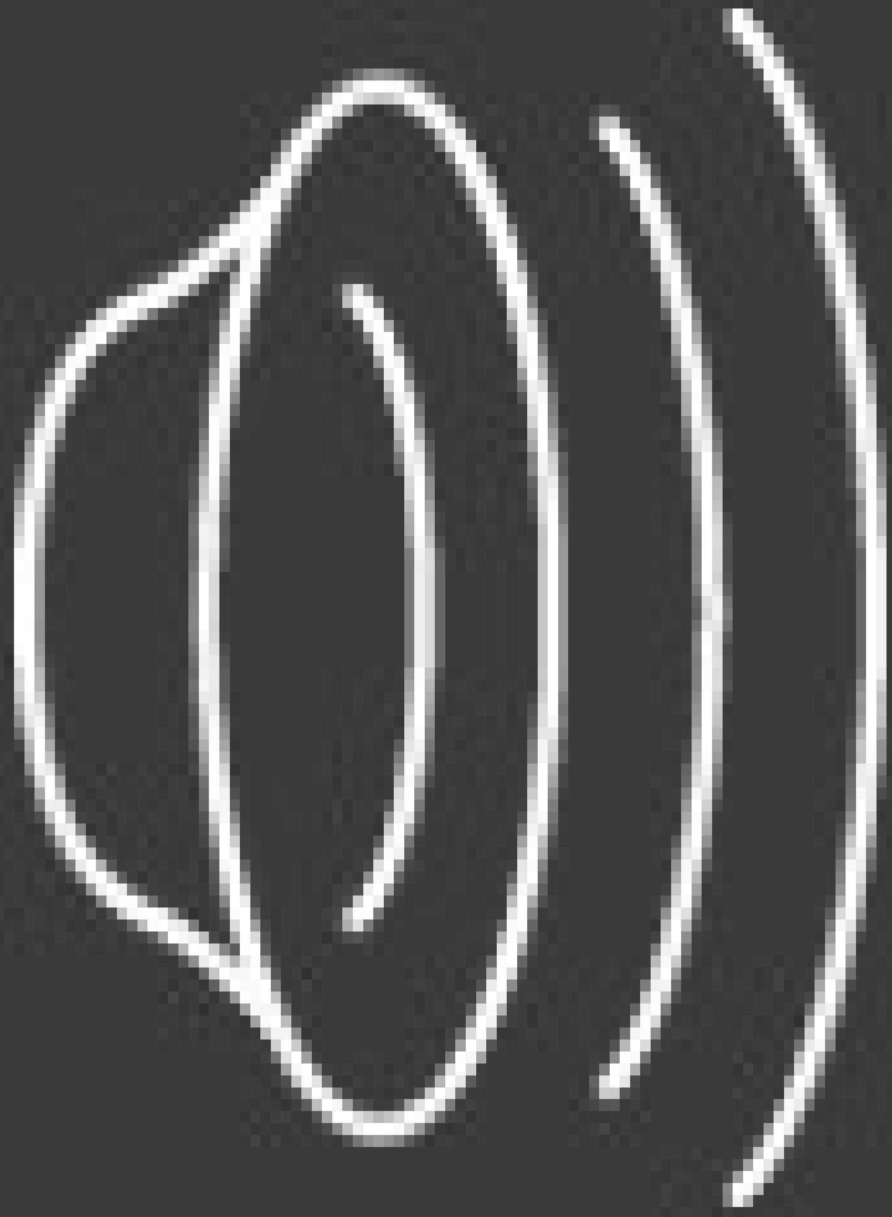
Pluto After New Horizons (natural color)

Pluto in Enchanced Color

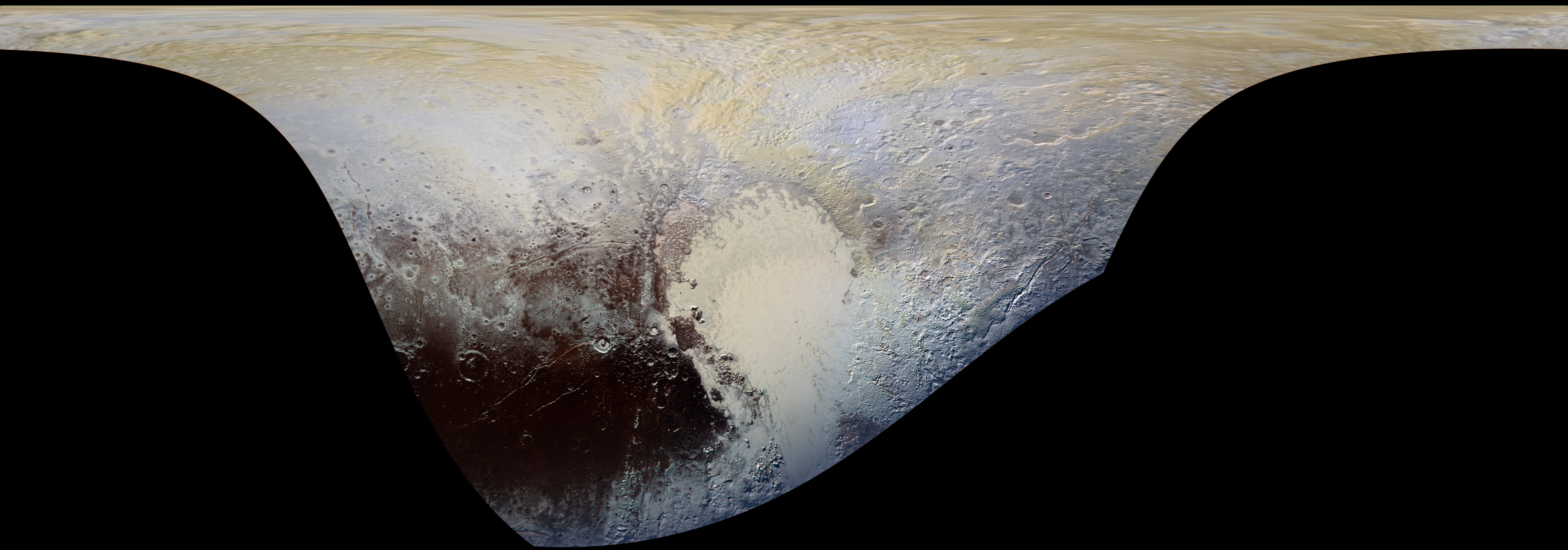
[redacted]

[redacted]

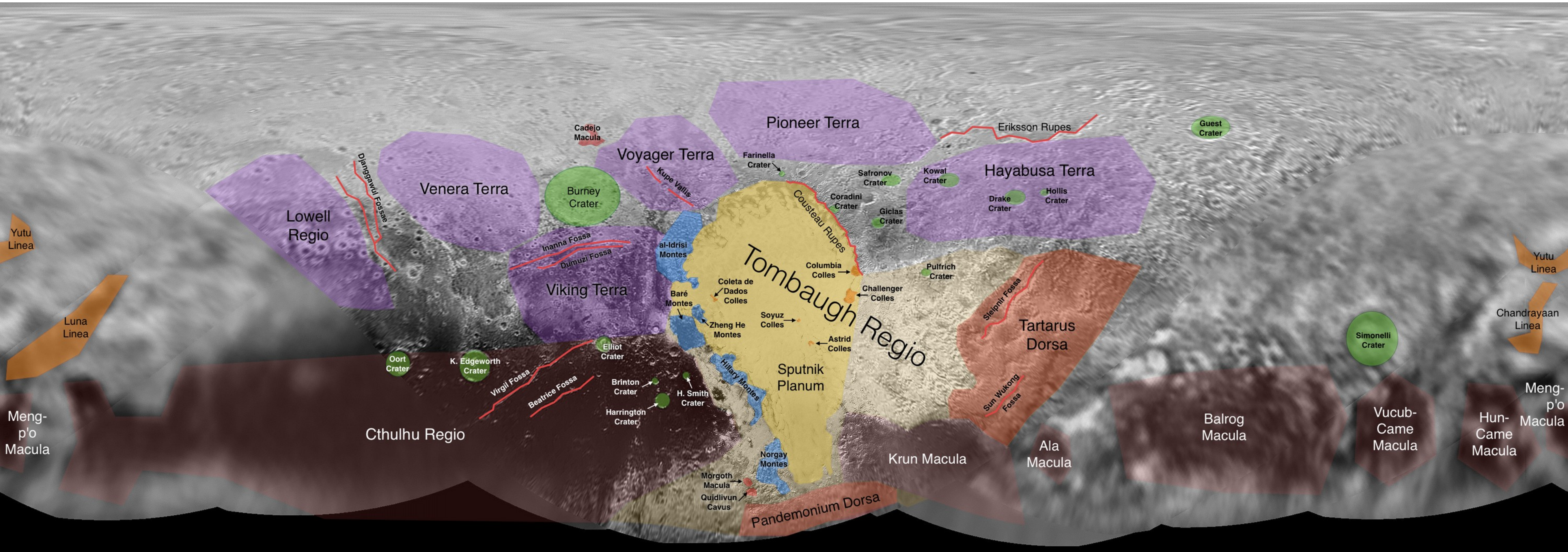
Pluto Movie



Pluto Cylindrical Projection Map in Enchanced Color

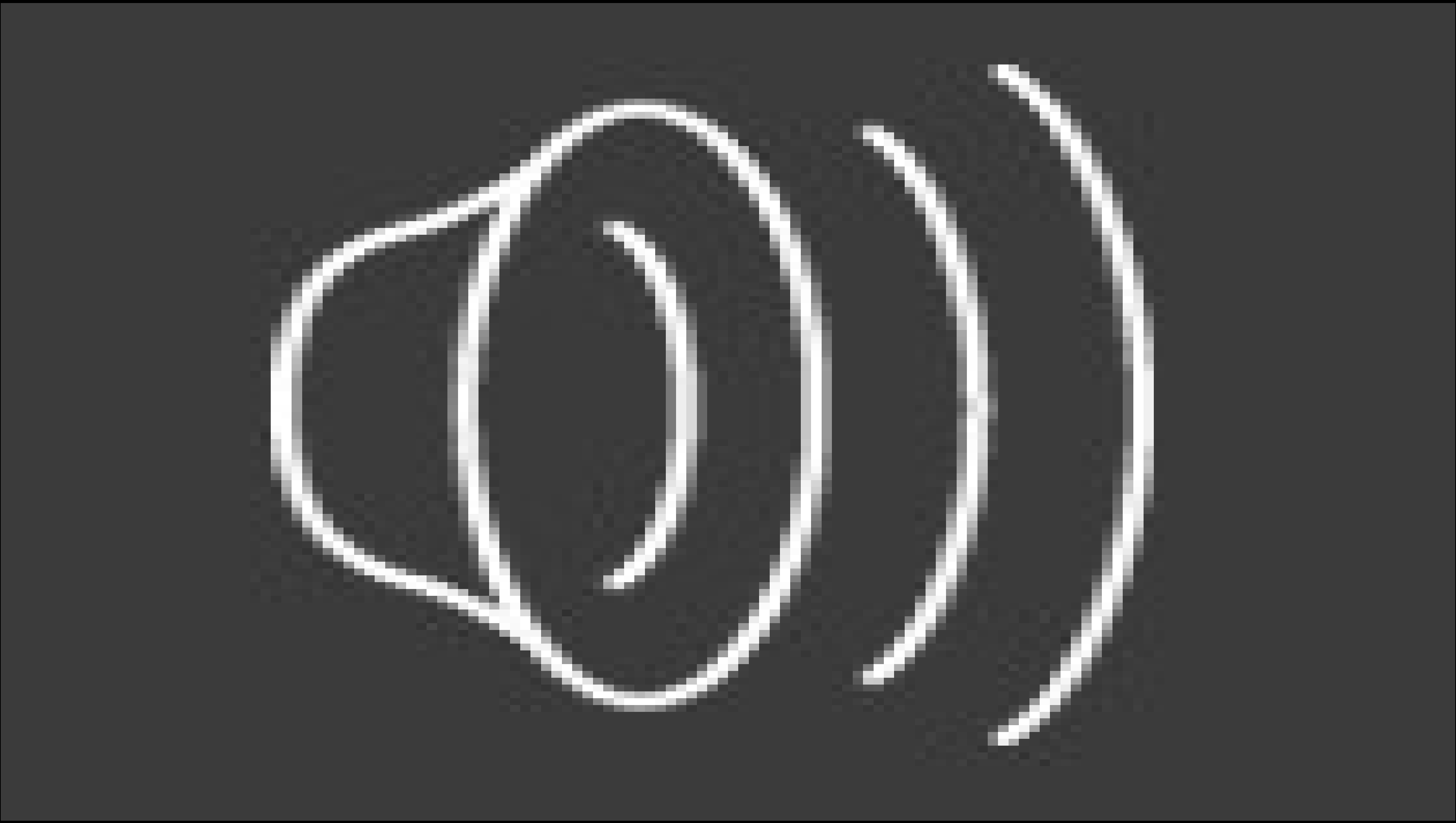


Annotated Pluto Map

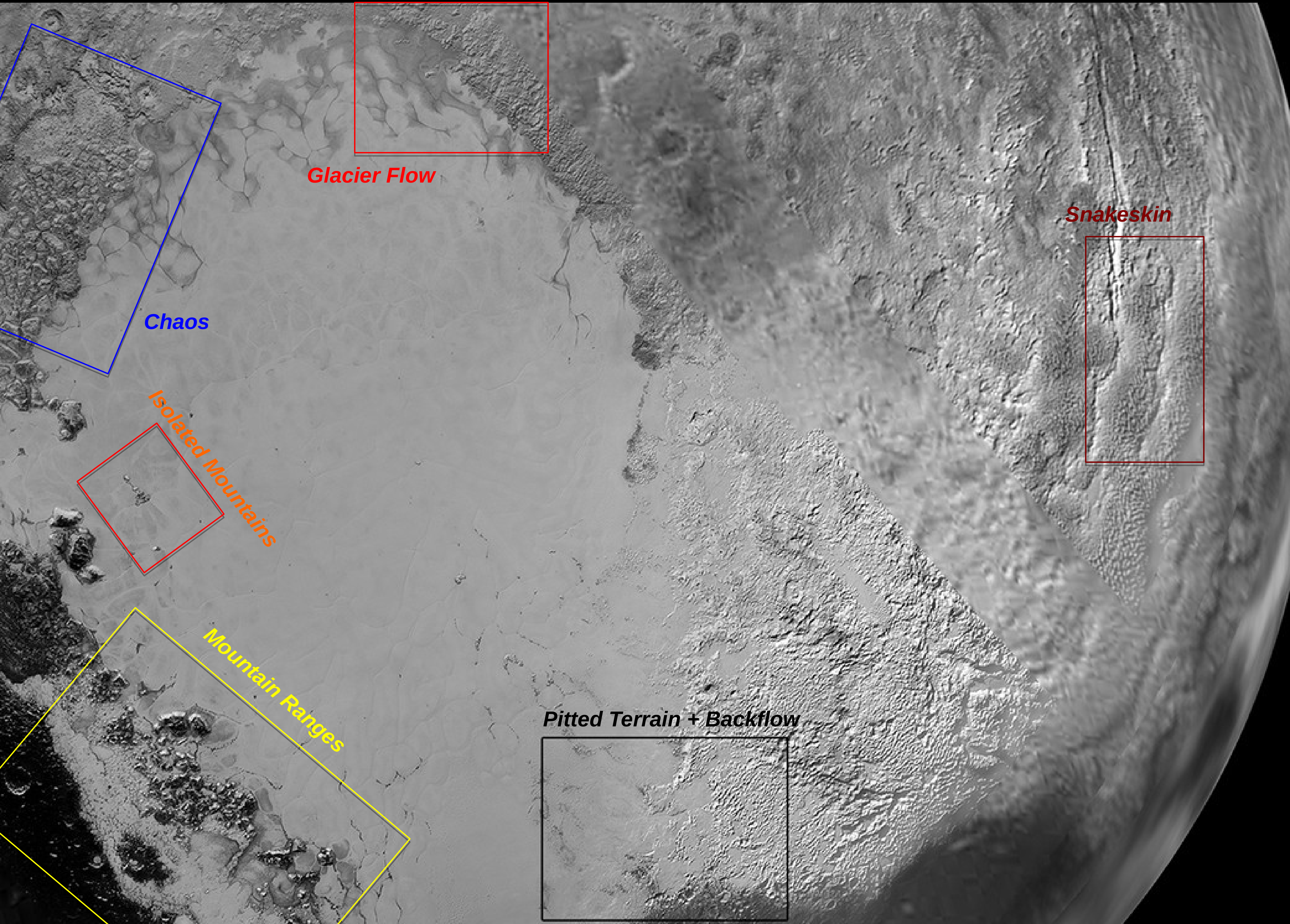


Informal Names for Features on Pluto

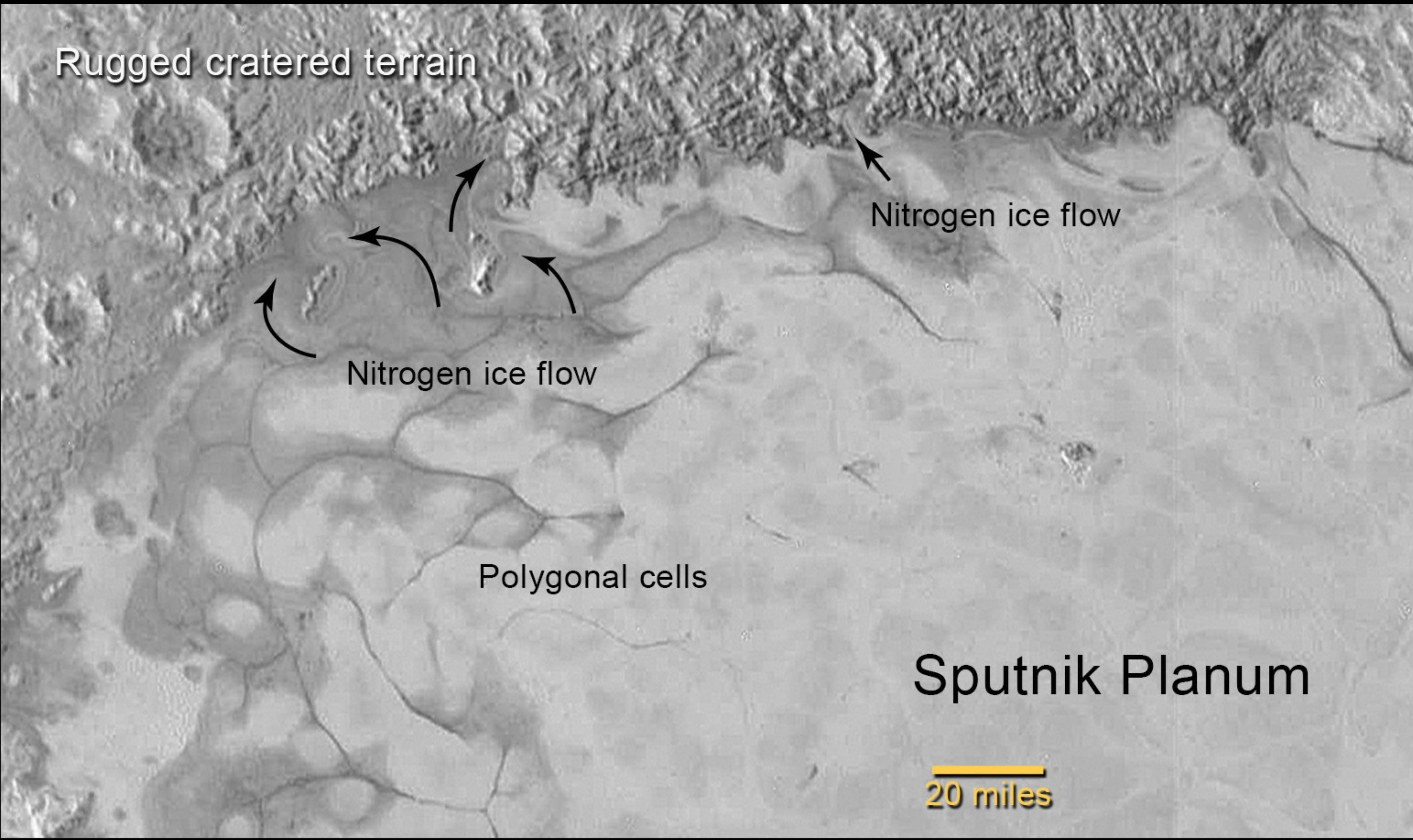
Sputnik Planum Flyover Movie



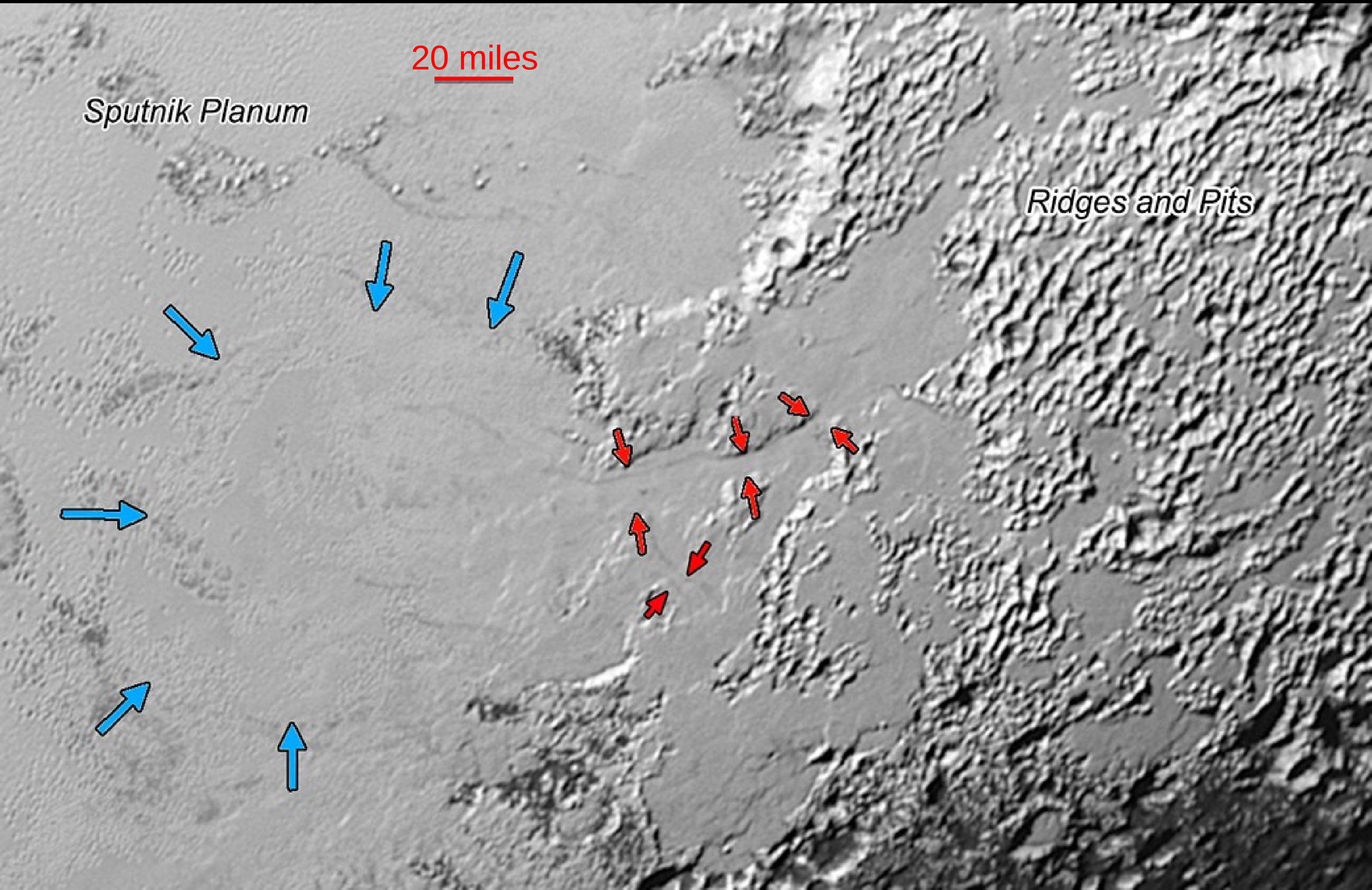
Look More Closely at Boxed Regions : Amazing Diversity



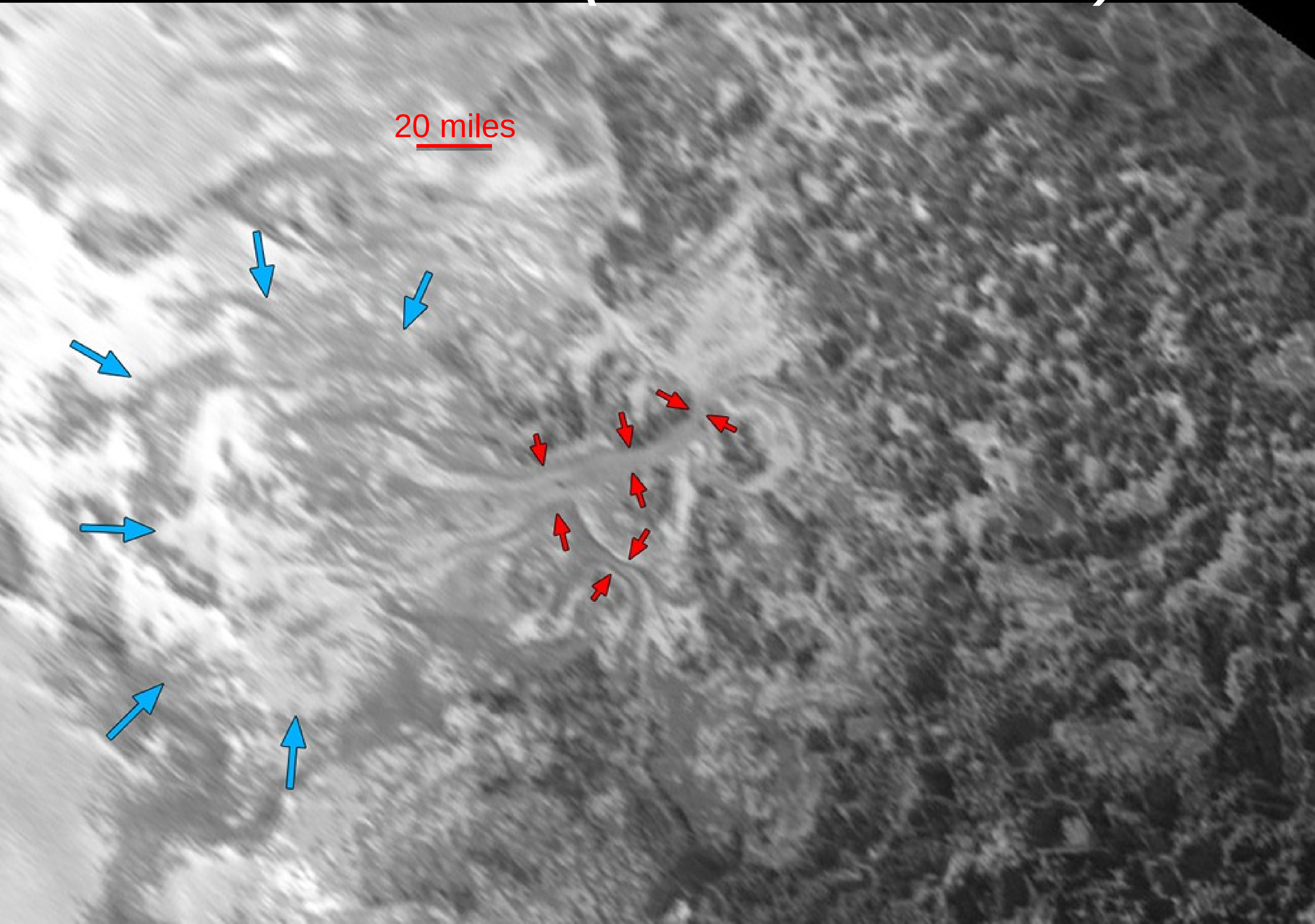
Glacier Flows on Pluto



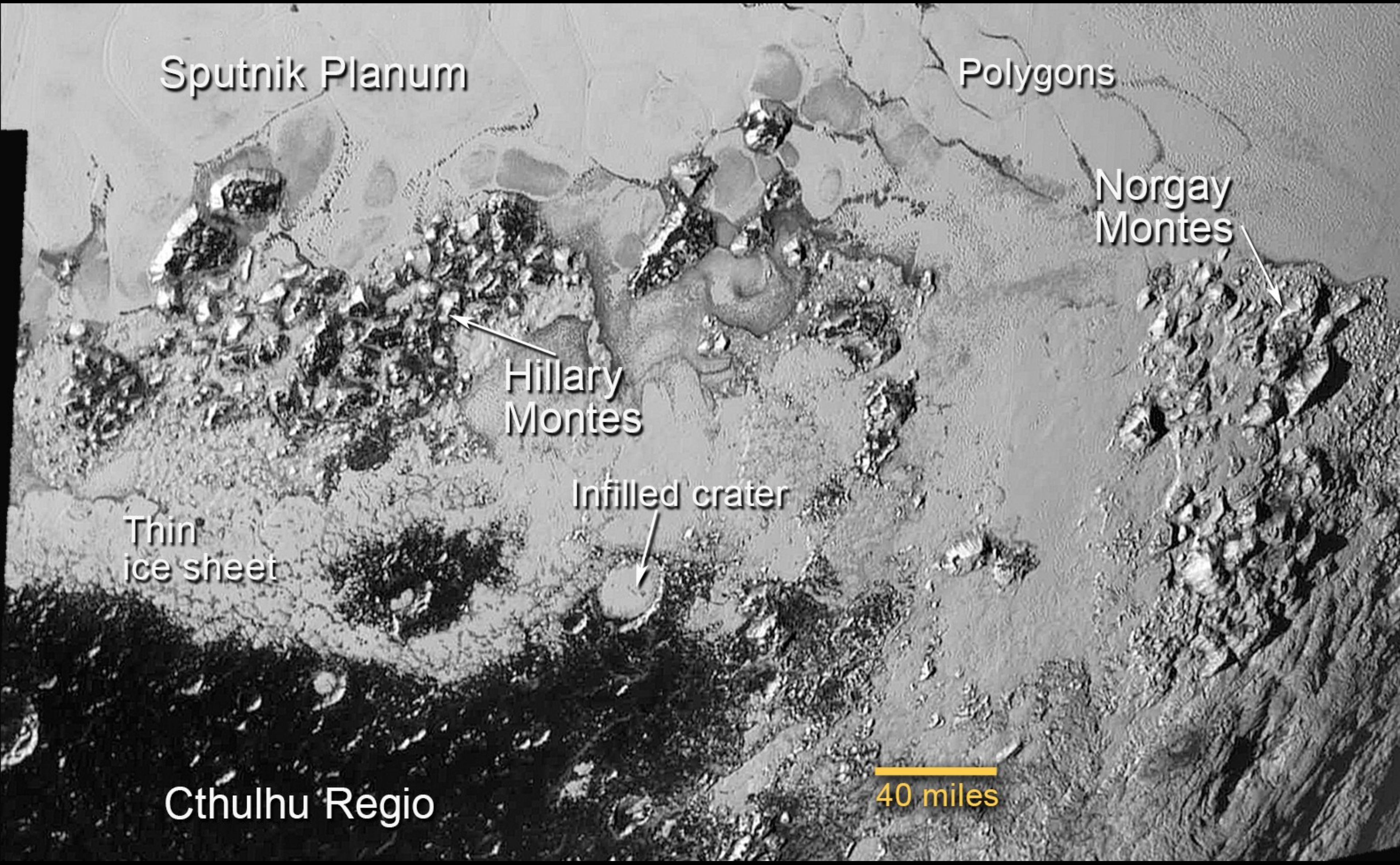
Pluto Flow Channels (high Sun illumination)



Pluto Flow Channels (low Sun illumination)

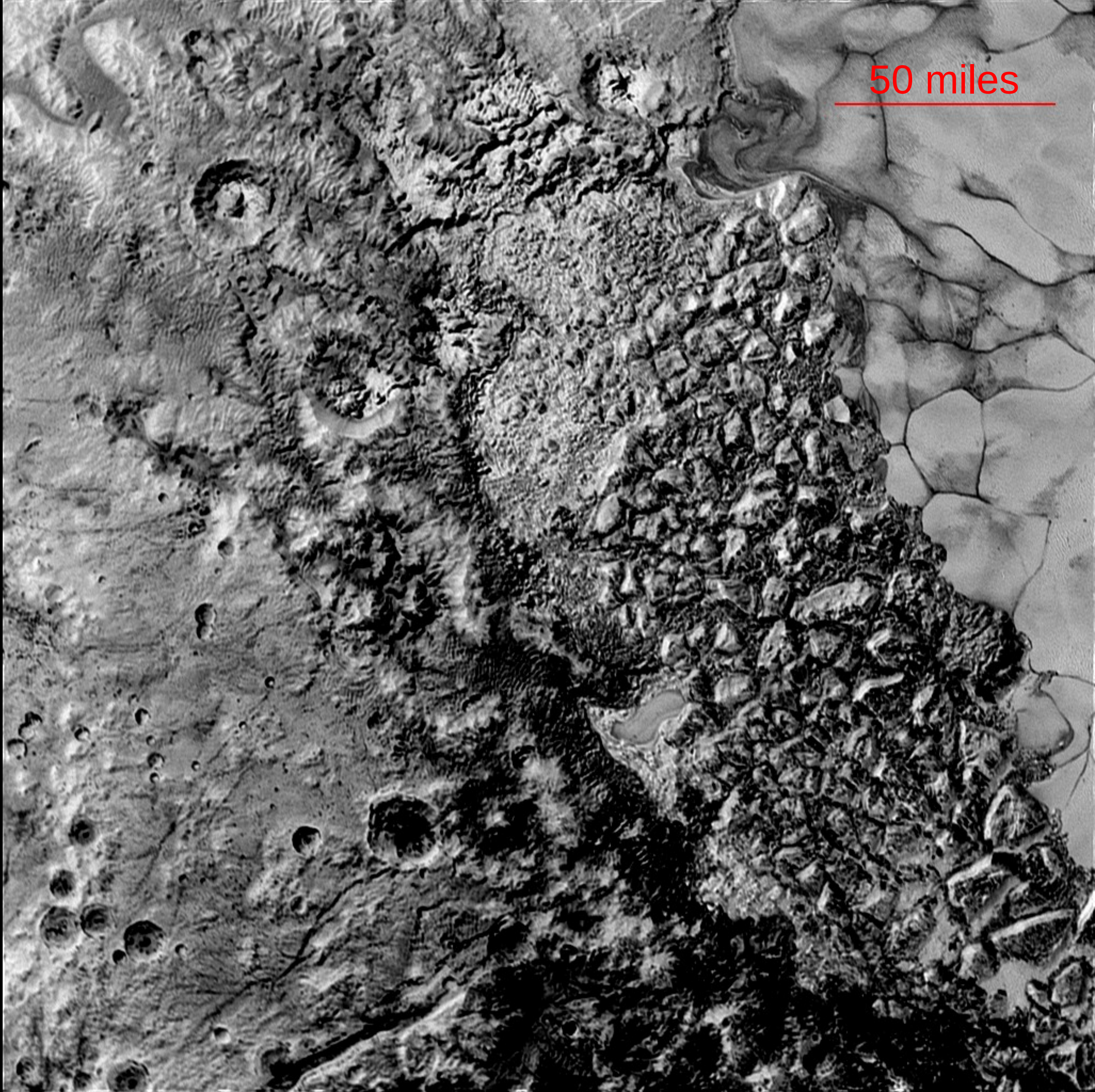


Pluto Geology: Ice Mountains 11,000 ft high

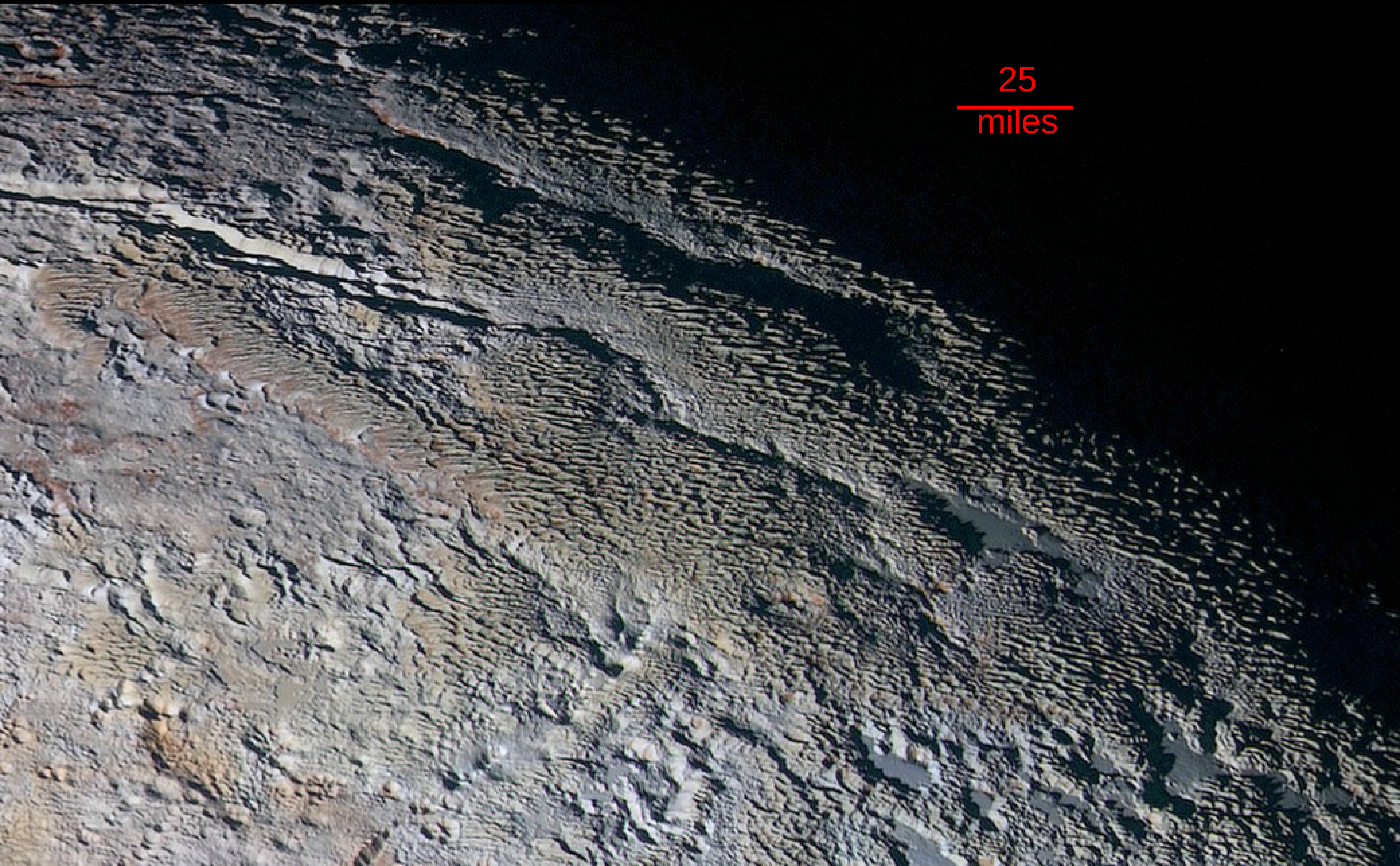


“Chaos” on Pluto:

Giant Floating Icebergs



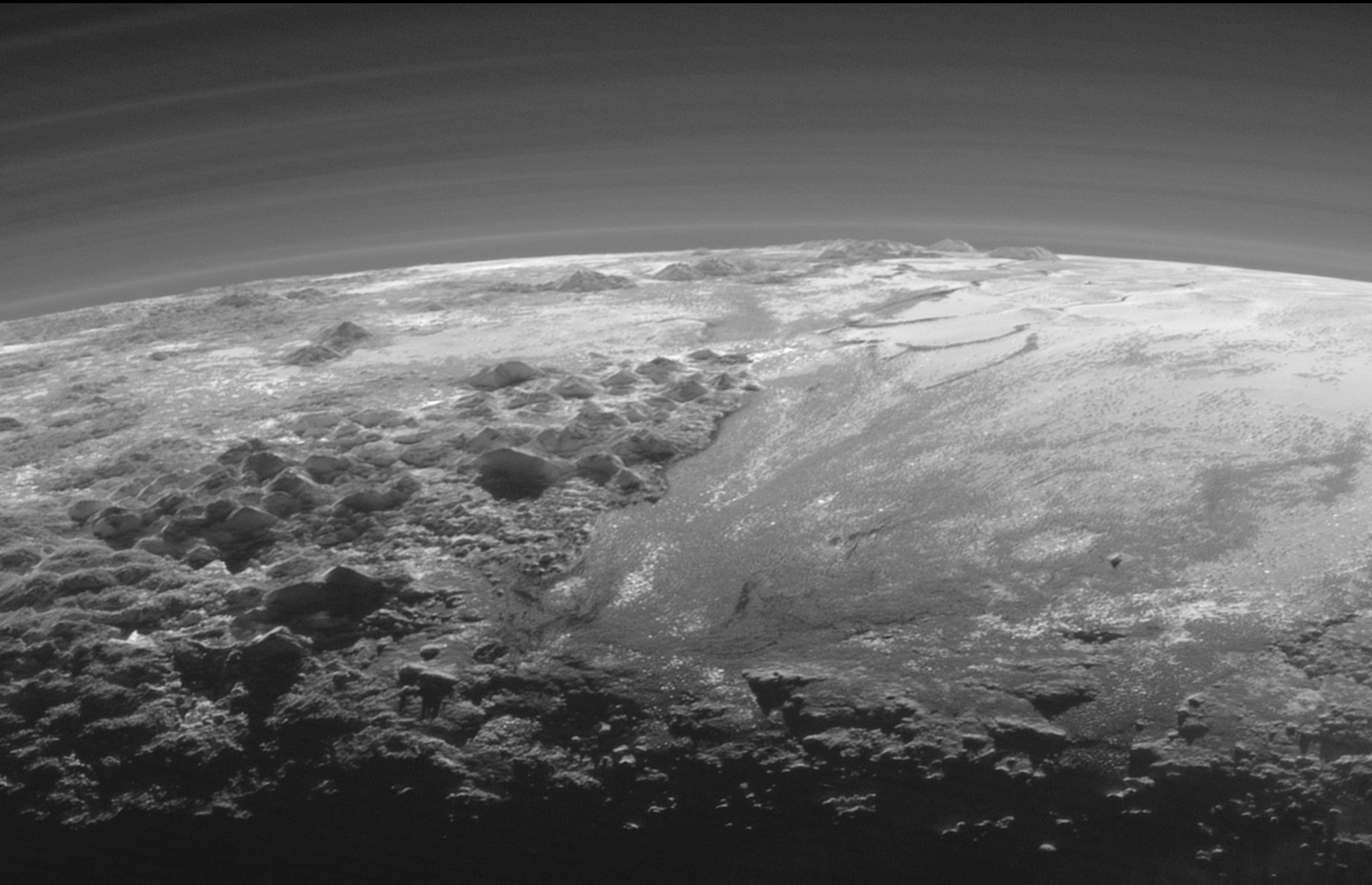
Pluto Tartarus Dorsa (“Snakeskin”)



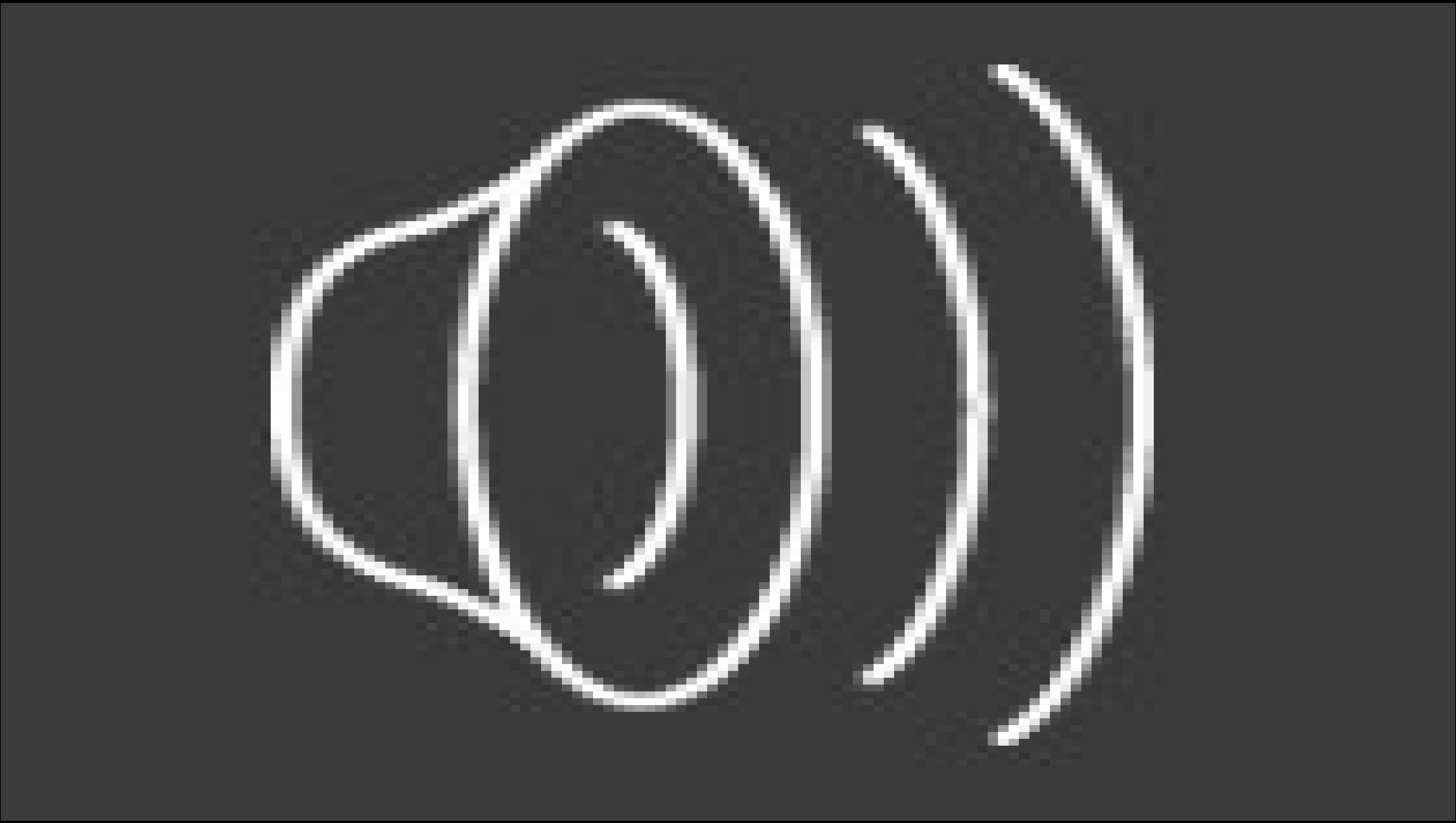
Pluto Plains & Isolated Mountains

Pluto Panorama with Haze Layers

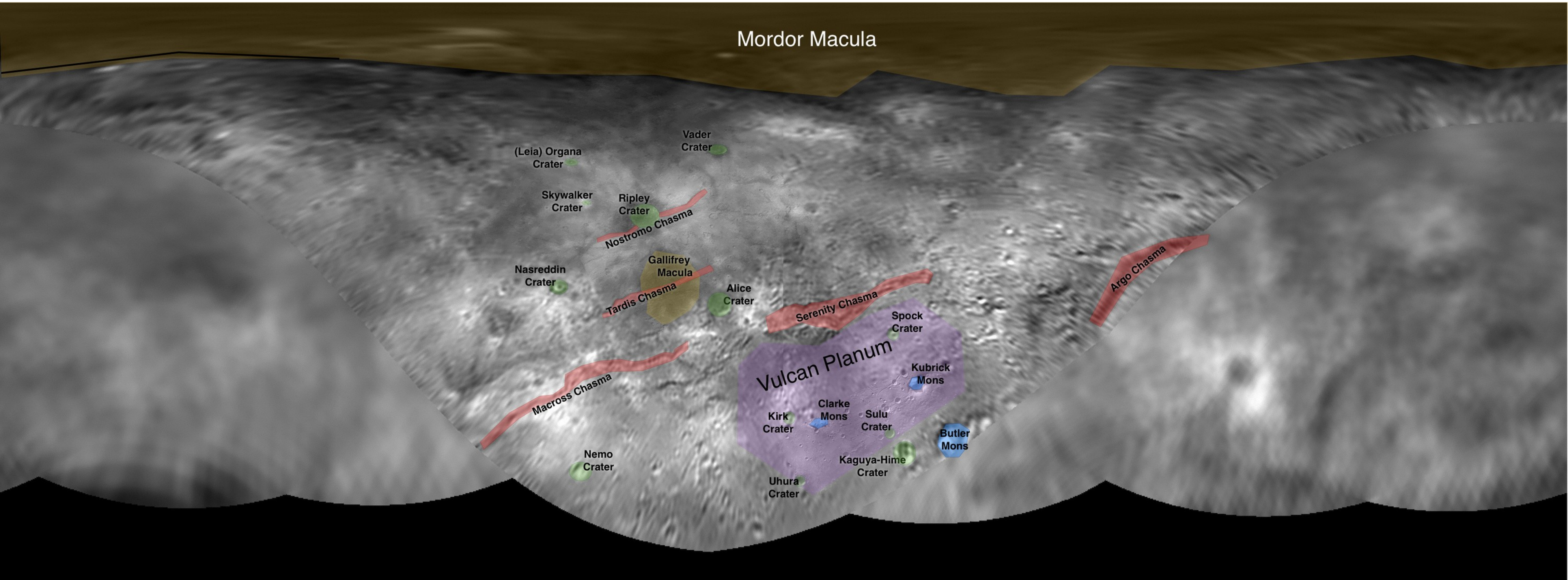
Mountains and Glaciers and Haze, Oh My!



Charon Flyover Movie



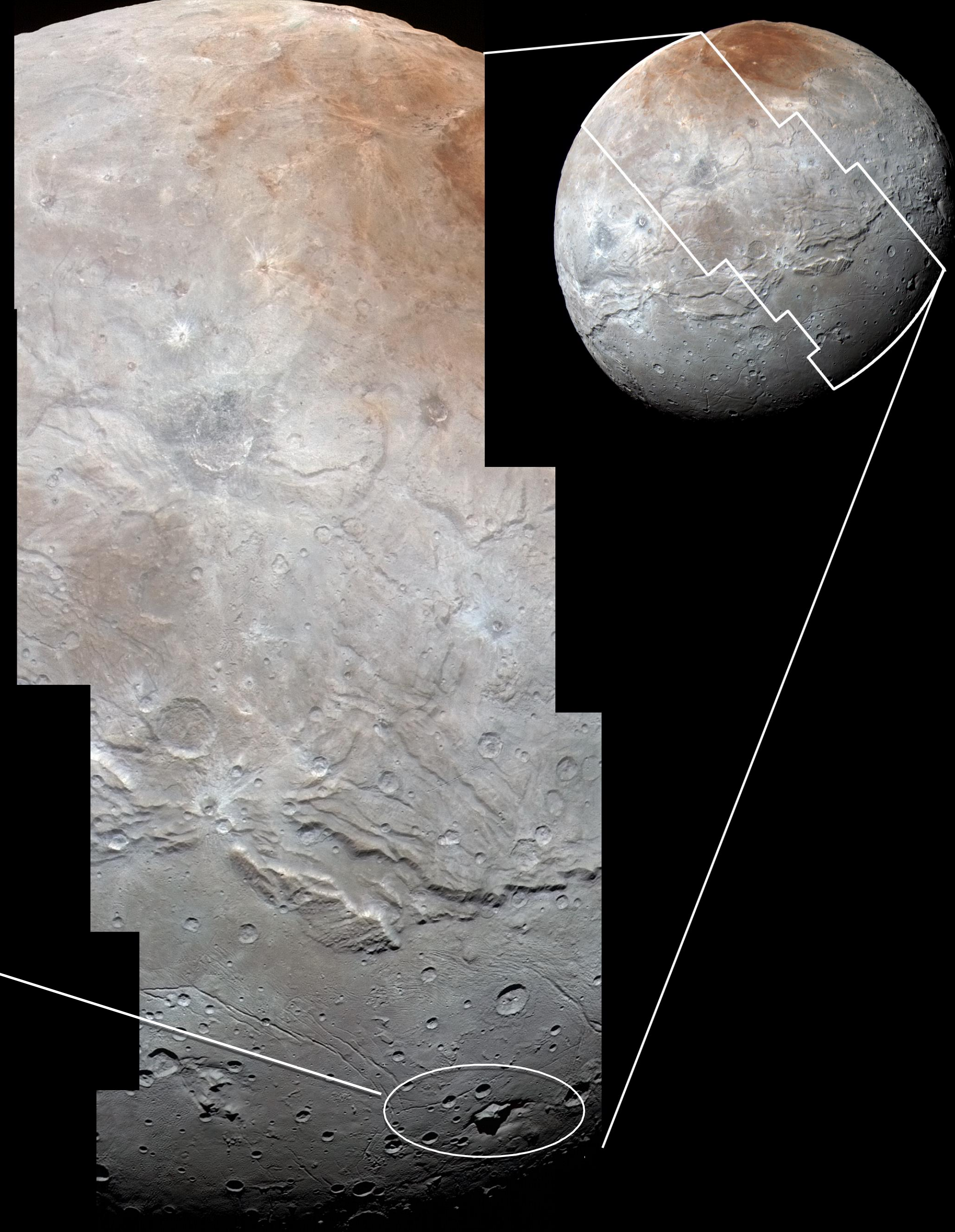
Annotated Charon Map



Informal Names for Features on Charon

Charon in Enhanced Color and HD

Charon : LORRI-MVIC Combo Even Higher Res



Mountain in a Moat : Kubrick Mons

Pluto and Charon

Two very different worlds

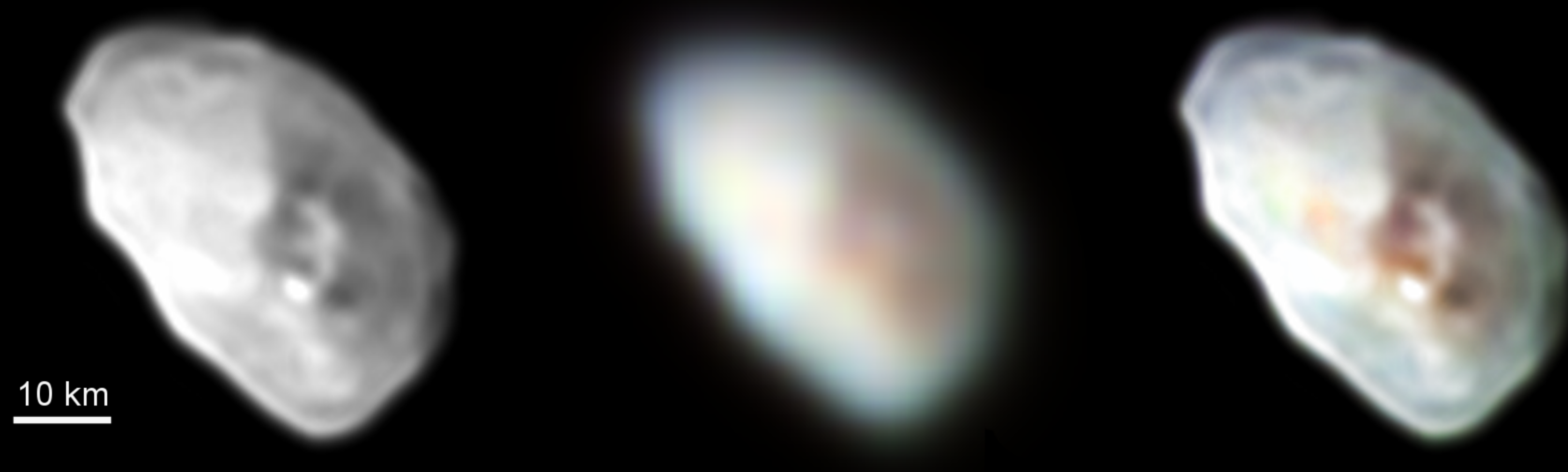
Three Faces of Nix from *New Horizons*

On Approch
July 13, 23:19 UTC

Second-best Image
July 14, 08:05 UTC

Departing
July 14, 14:55 UTC

Pluto's moon Nix
as seen by *New Horizons*

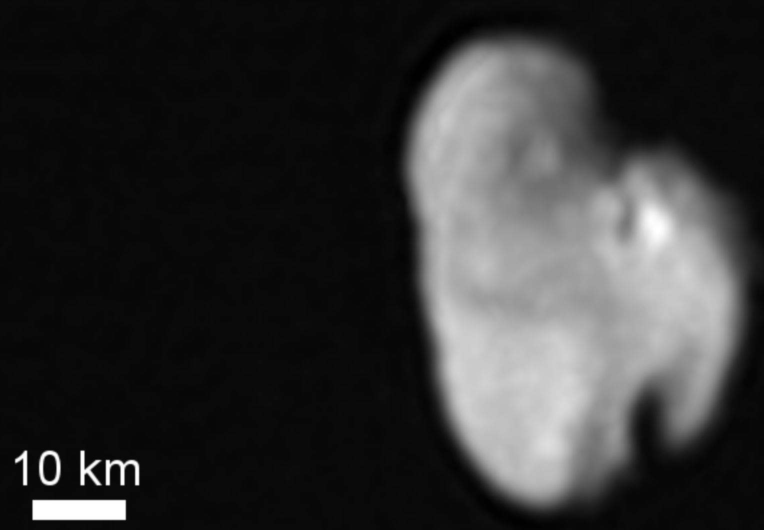


LORRI
Panchromatic

MVIC
Enhanced Color

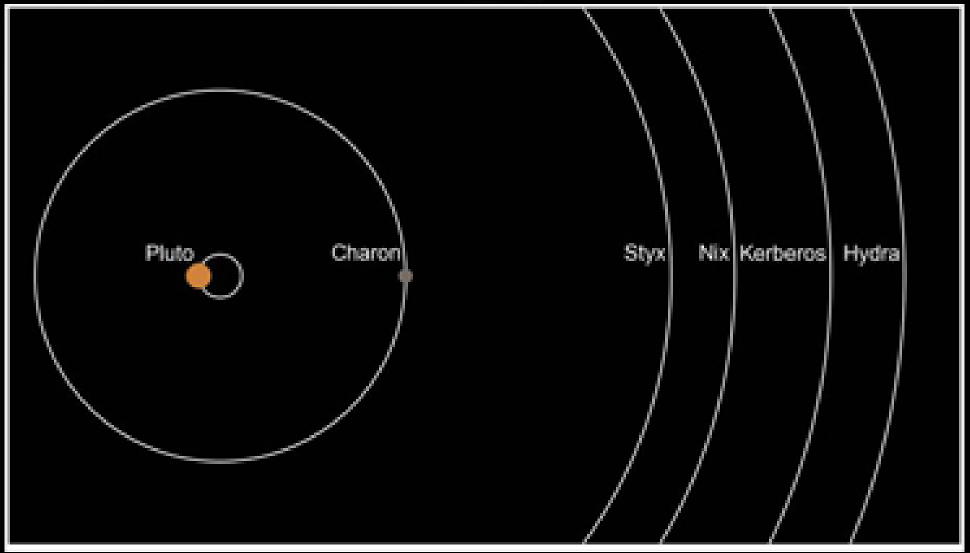
LORRI/MVIC
Composite

Pluto's moon Hydra as seen by *New Horizons*



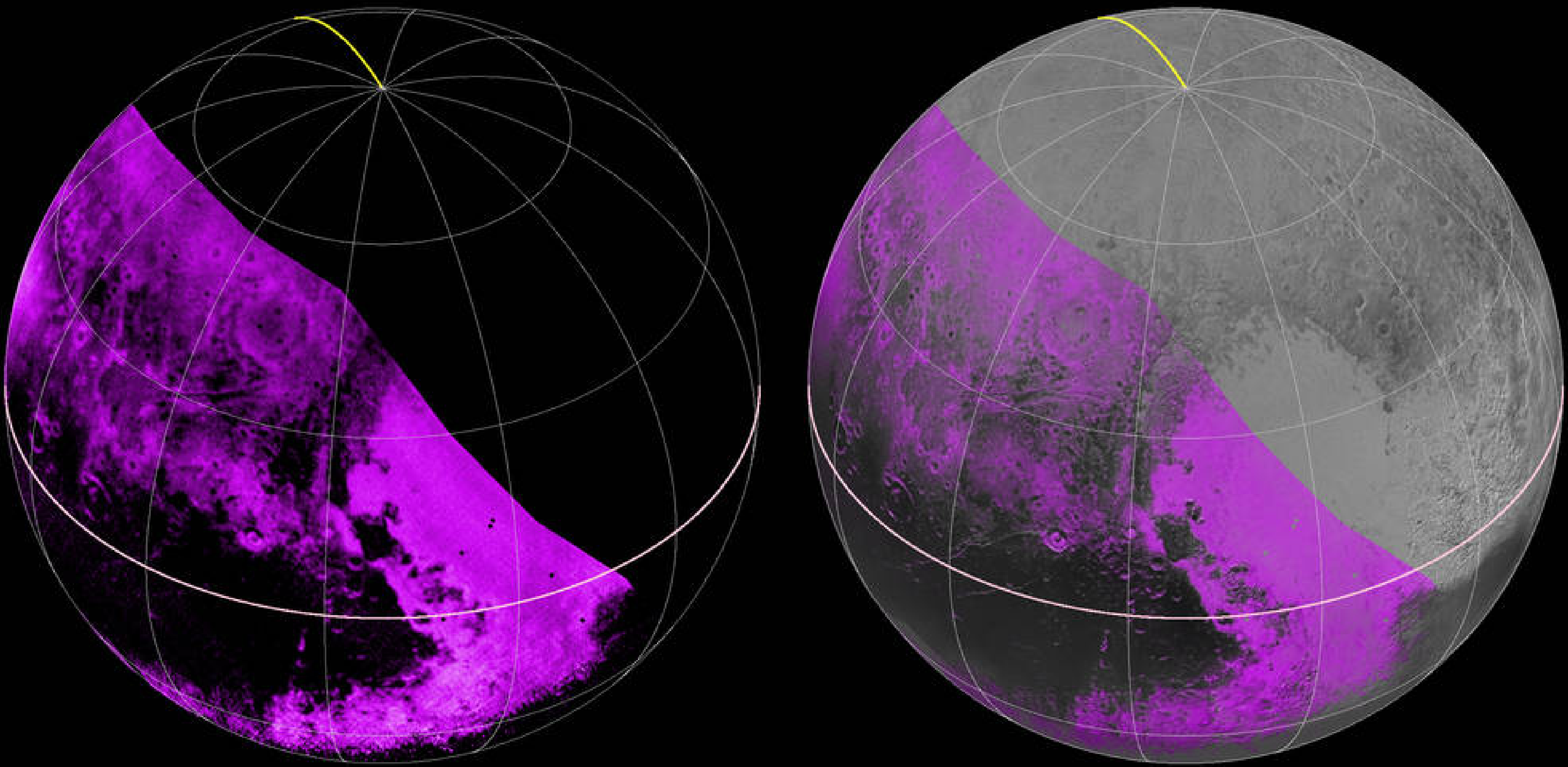
LORRI Panchromatic
July 14, 07:40 UTC

Picking up Styx

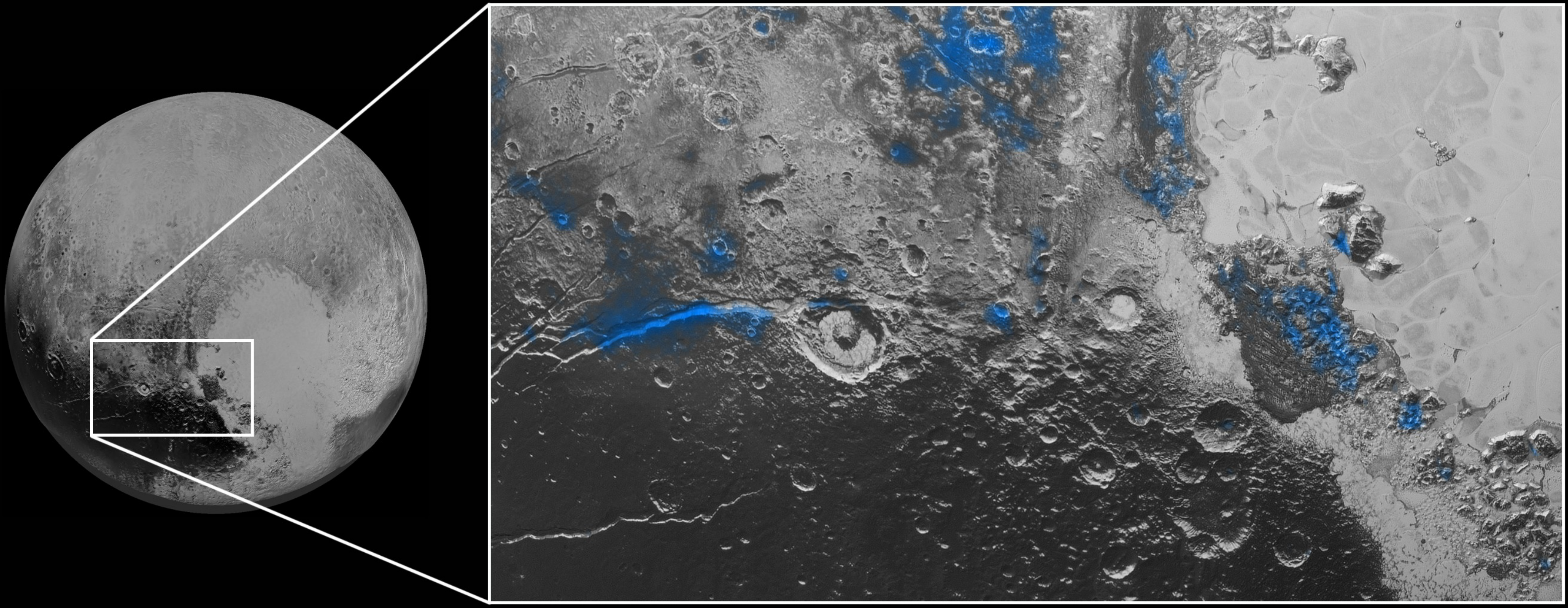


Composition Results

Pluto Methane Map



Water Ice Discovered on Pluto



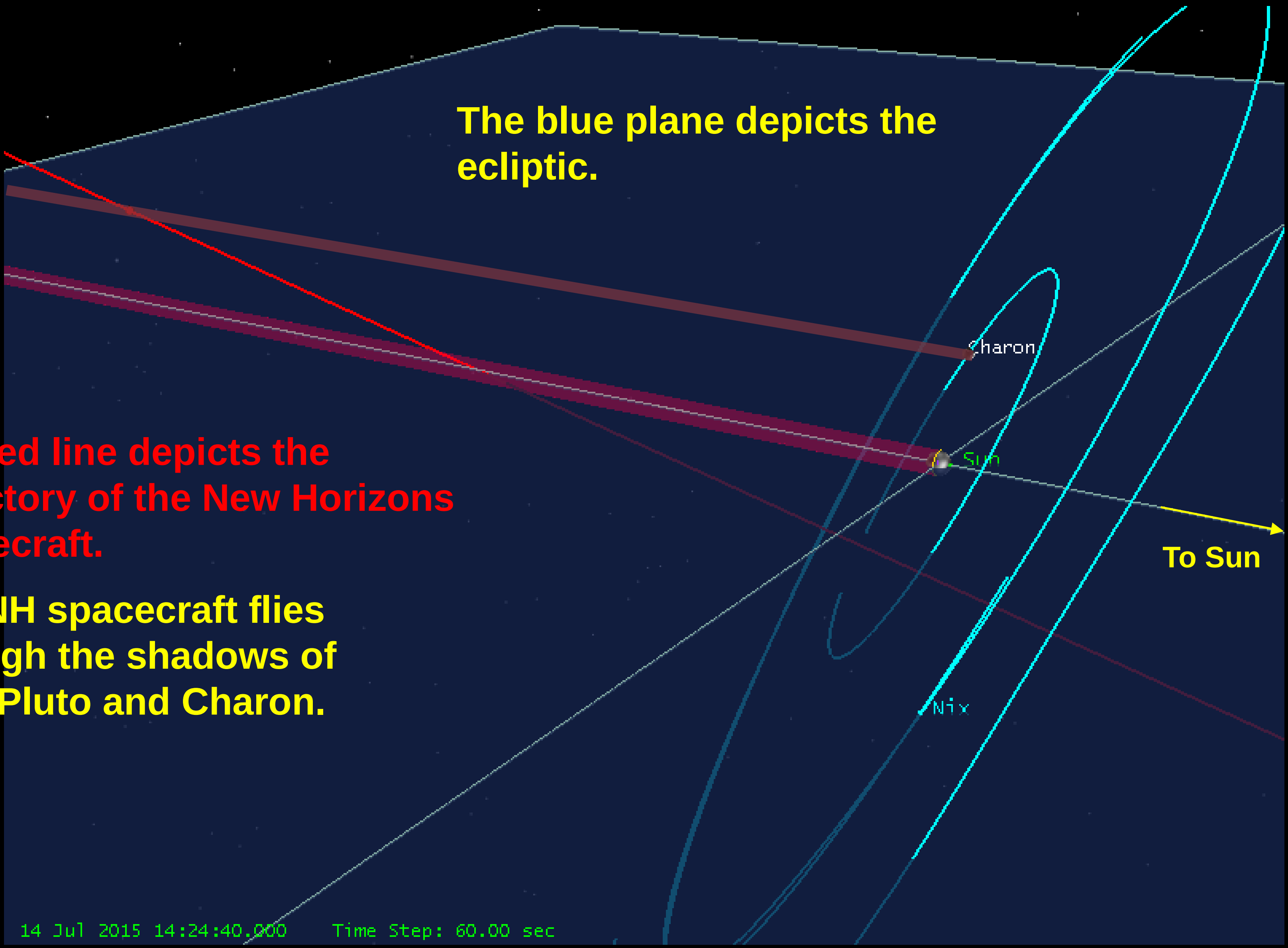
Atmospheric Results

Pluto Encounter Geometry

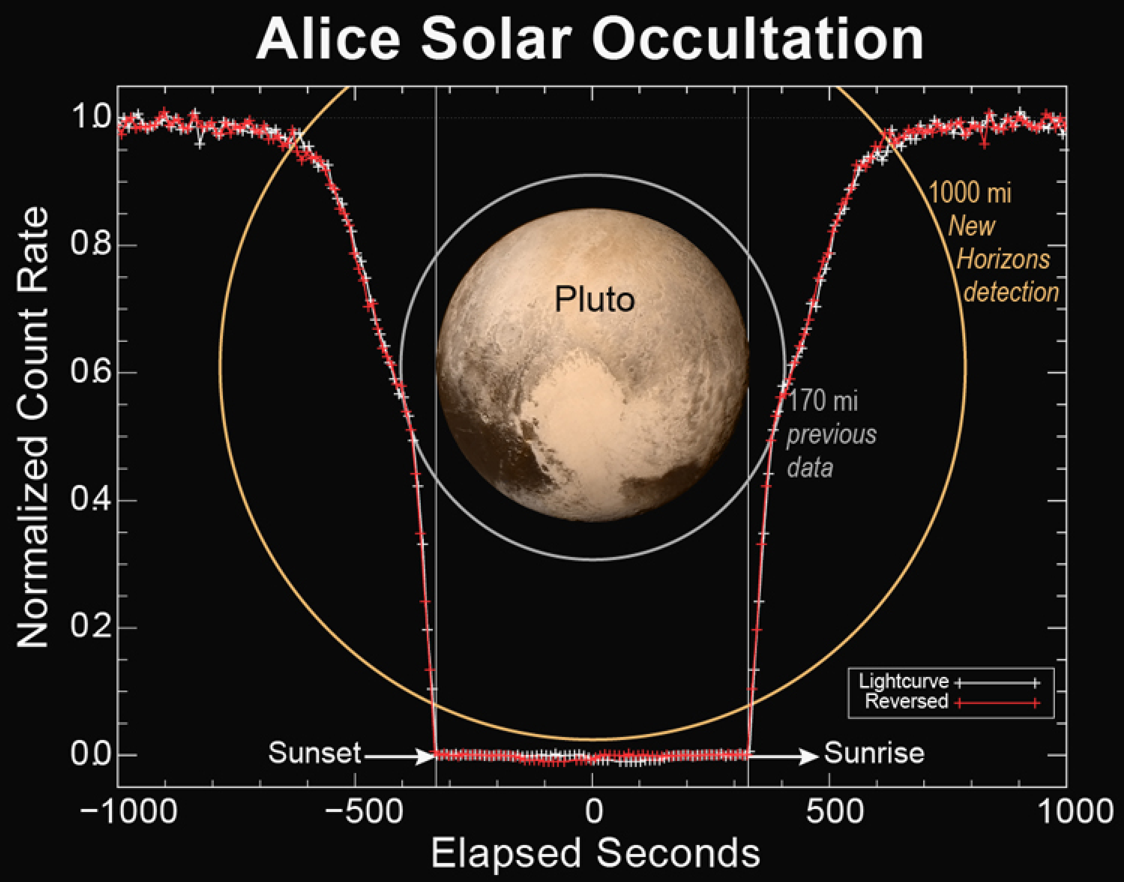
The blue plane depicts the ecliptic.

The red line depicts the trajectory of the New Horizons spacecraft.

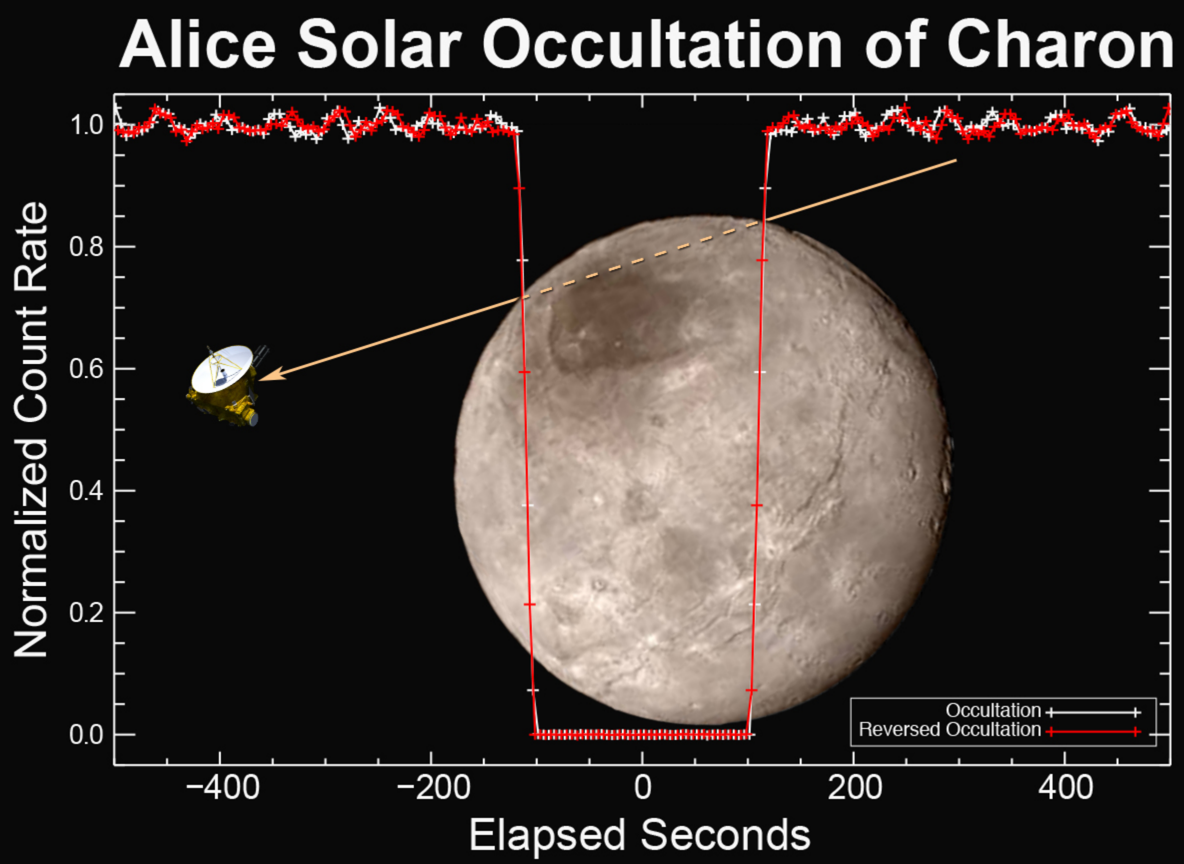
The NH spacecraft flies through the shadows of both Pluto and Charon.



Pluto UV Solar Occultation (Alice)



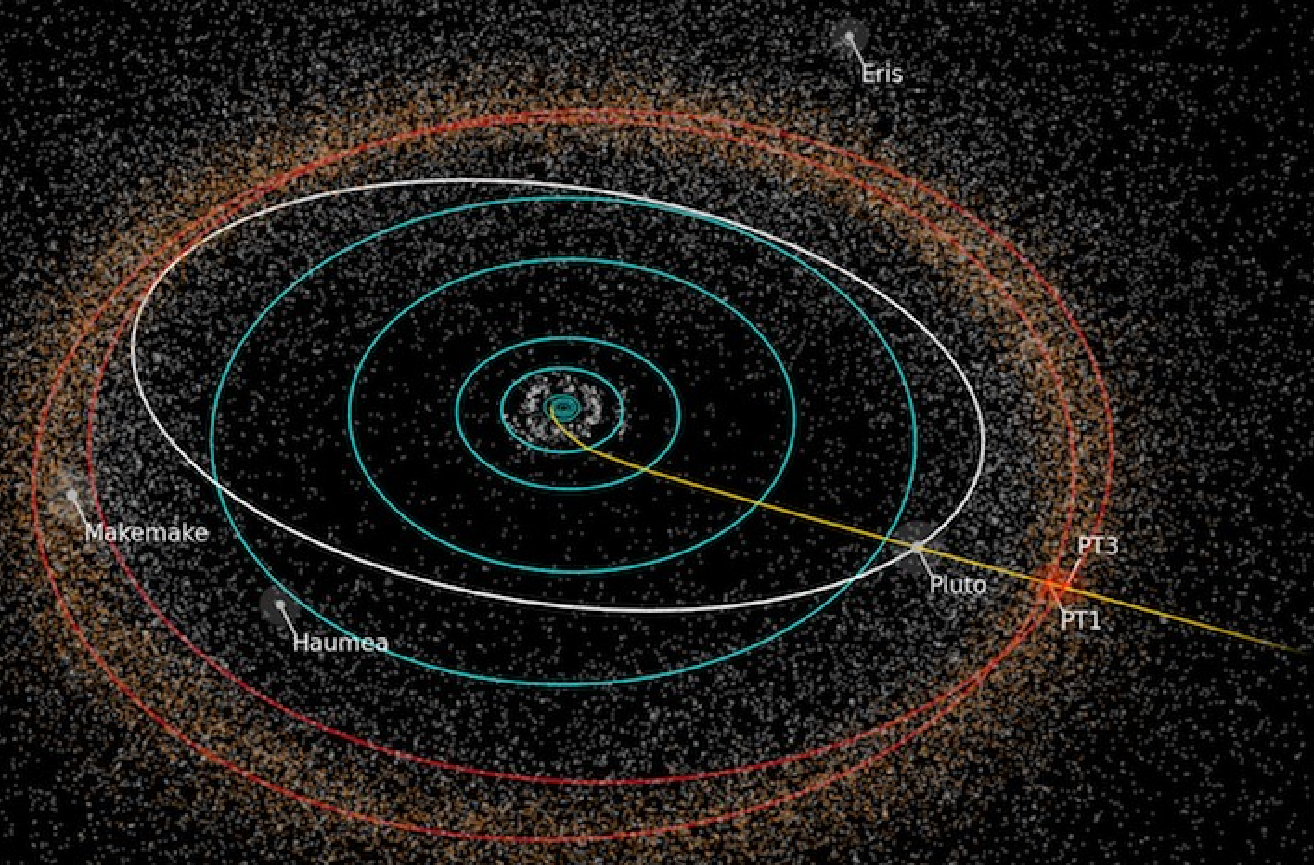
Charon UV Solar Occultation



Pluto's Blue Sky!

After Pluto : *Potential* KBO Flyby Target

NASA TCM decision : Aim at PT1 = 2014 MU_{69}
Submit Extended Mission proposal in spring 2016
If approved, close flyby of PT1 on Jan 1, 2019

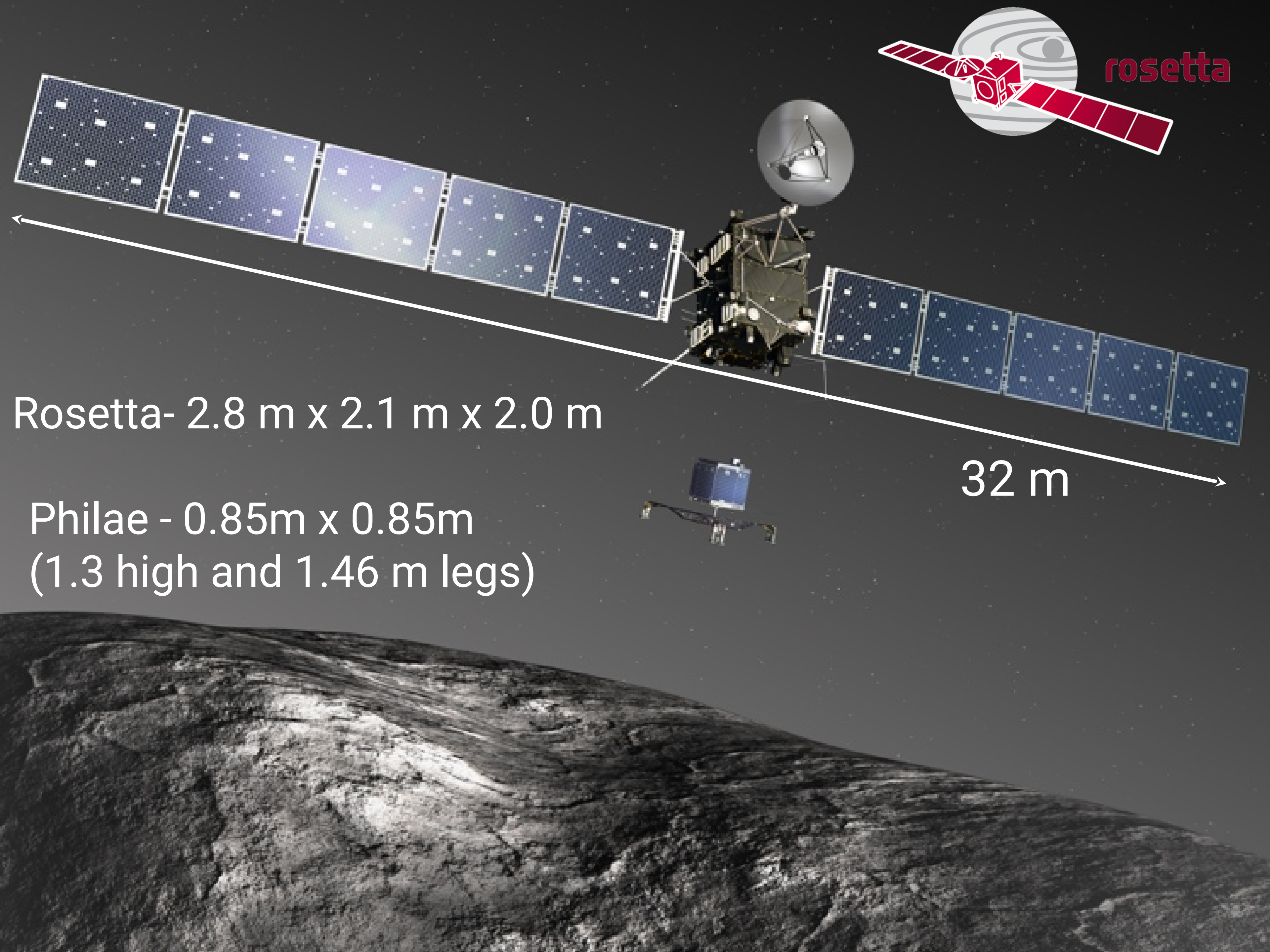


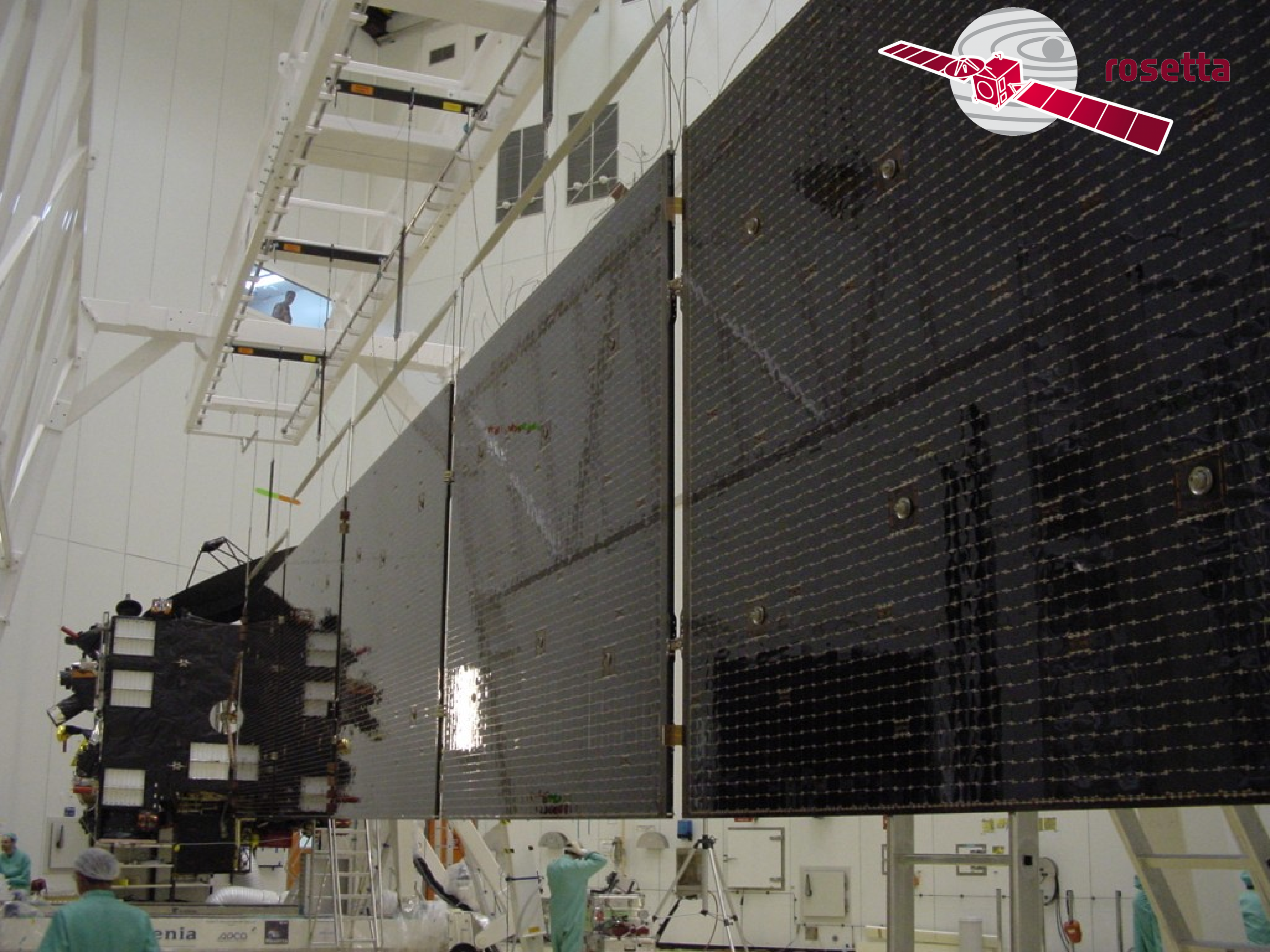
Visit our website:

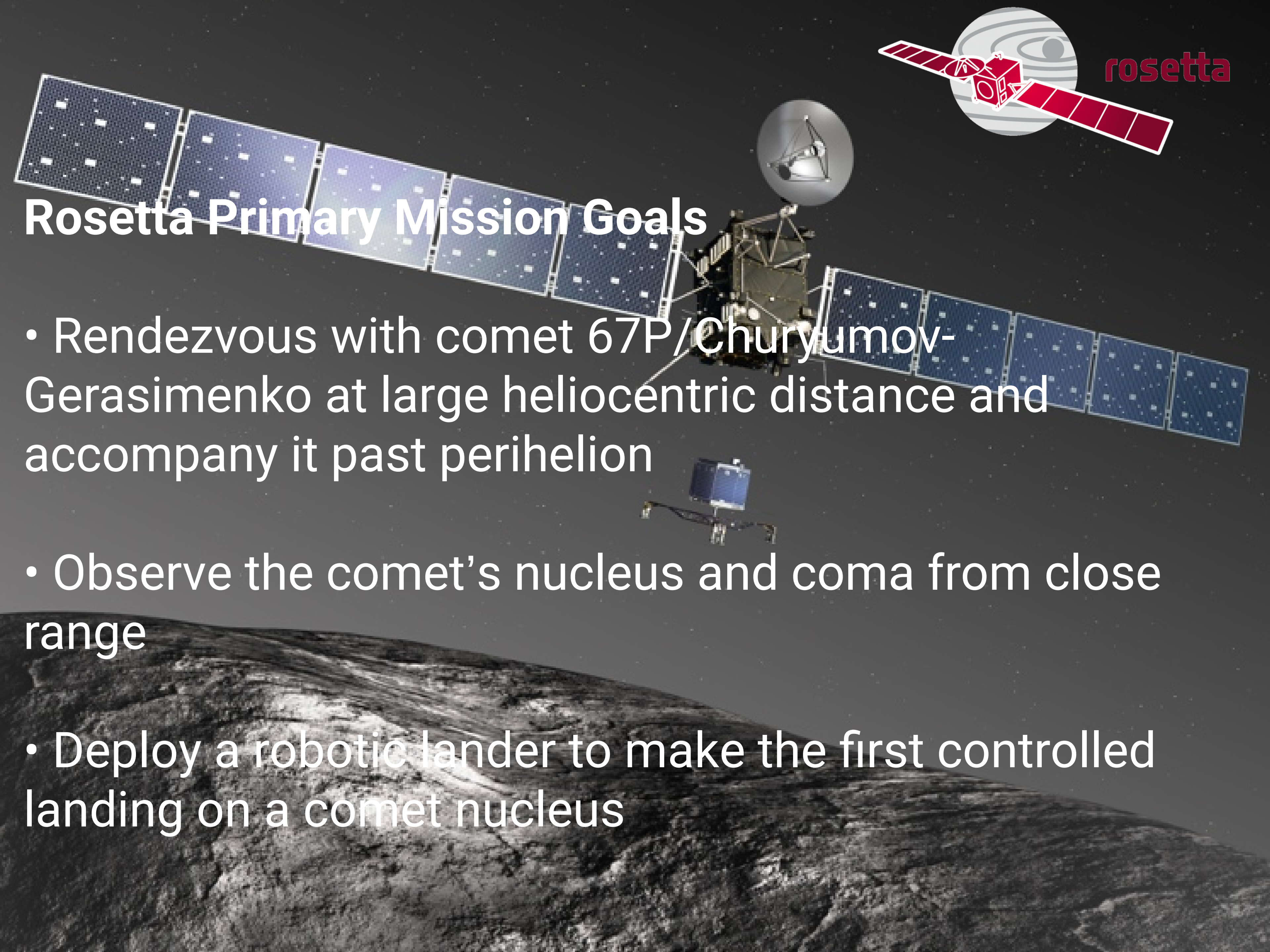
pluto.jhuapl.edu

Rosetta

(with great thanks to Stephan Ulamec)


rosetta
Rosetta- 2.8 m x 2.1 m x 2.0 m
32 m
Philae - 0.85m x 0.85m
(1.3 high and 1.46 m legs)


rosetta

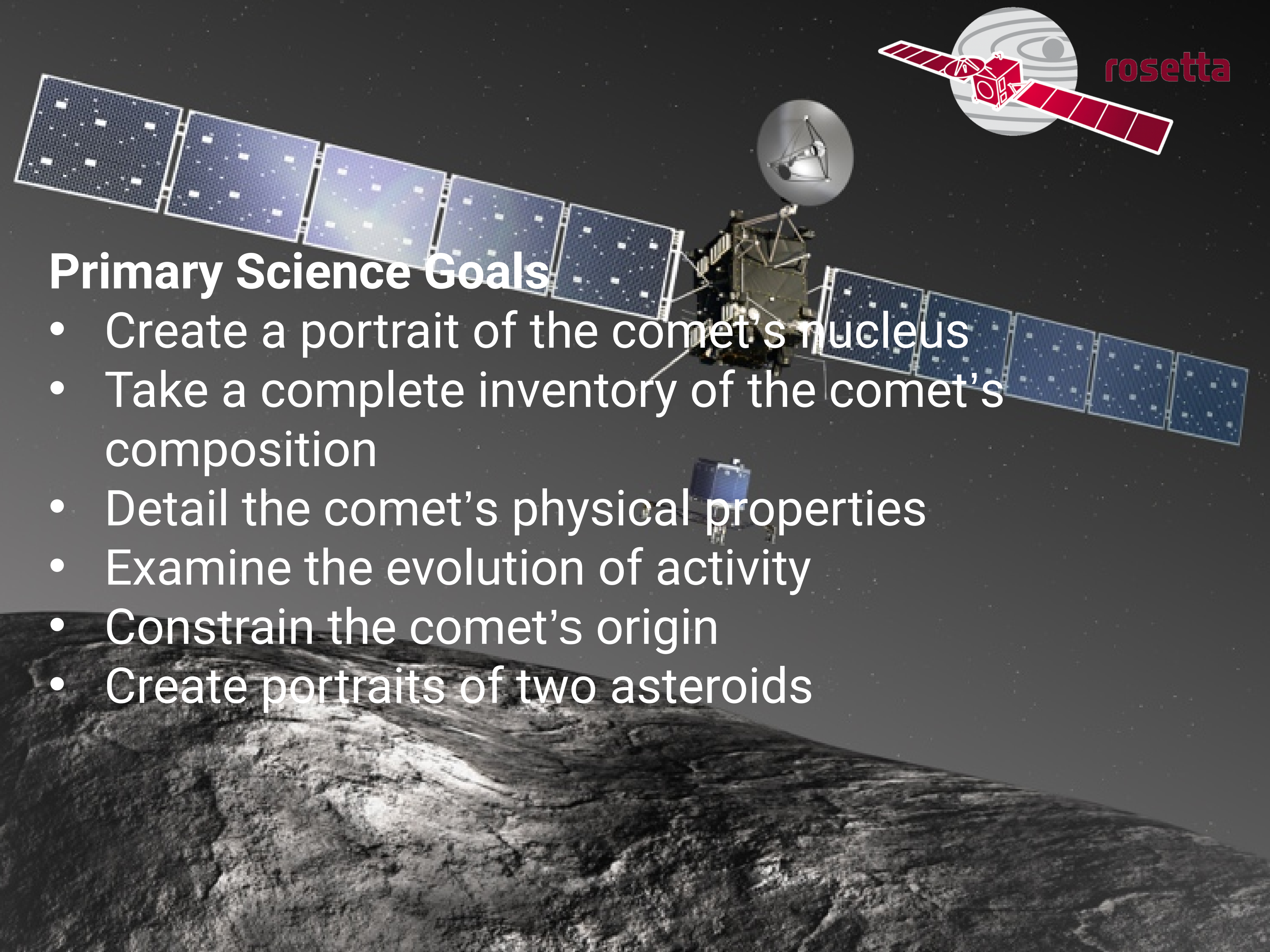


Rosetta Primary Mission Goals

- Rendezvous with comet 67P/Churyumov-Gerasimenko at large heliocentric distance and accompany it past perihelion

- Observe the comet’s nucleus and coma from close range

- Deploy a robotic lander to make the first controlled landing on a comet nucleus



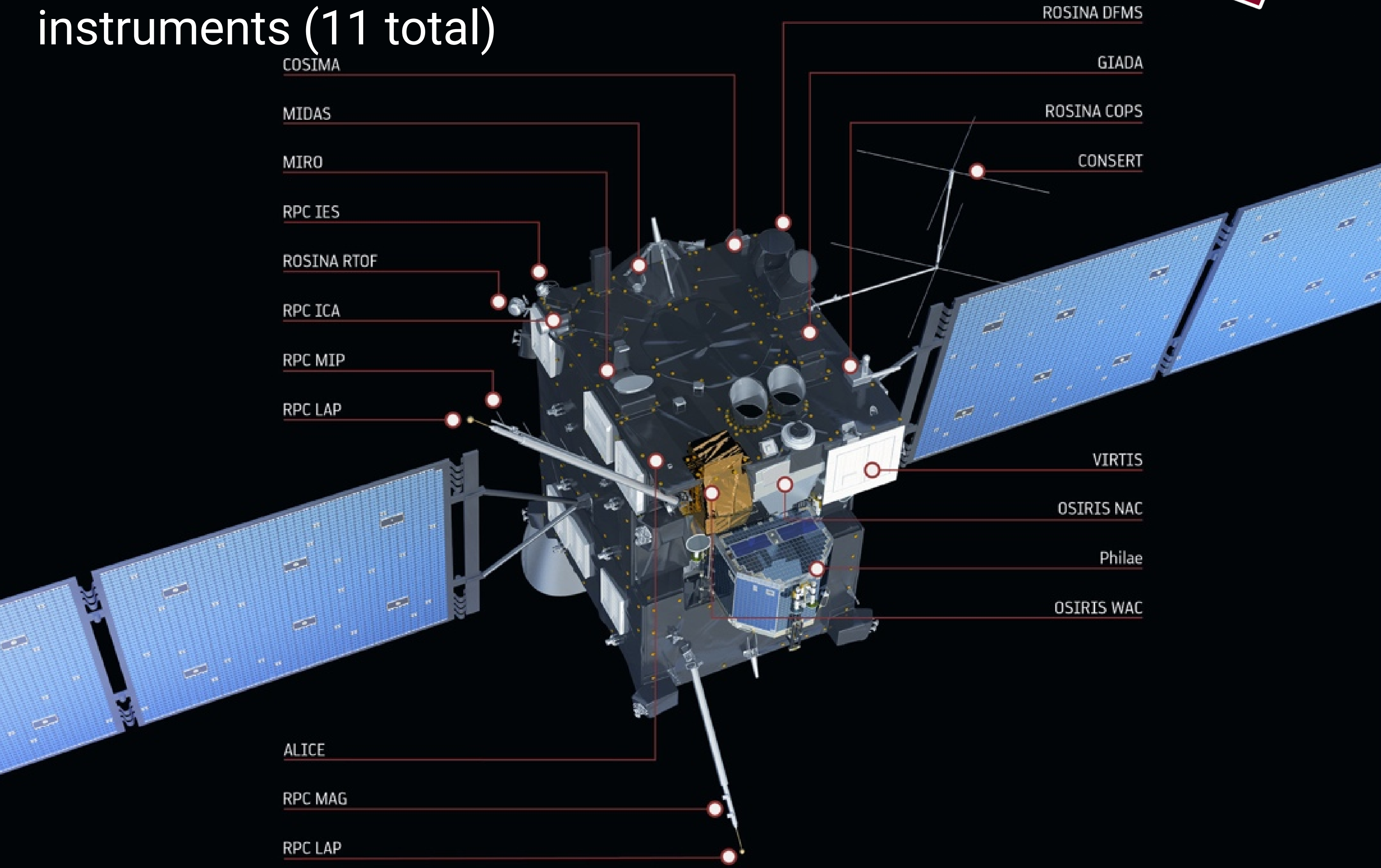
rosetta

Primary Science Goals

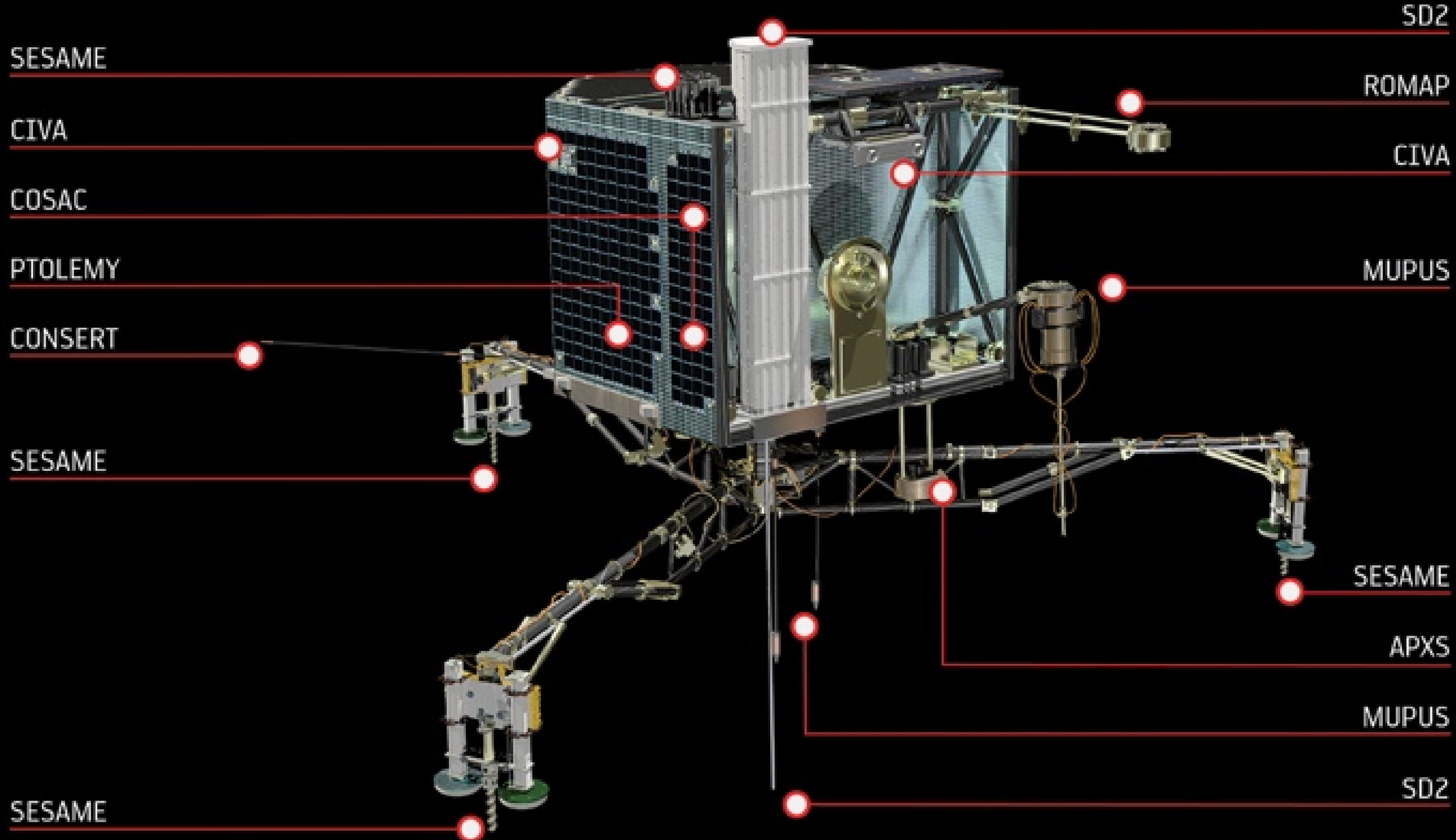
- Create a portrait of the comet's nucleus
- Take a complete inventory of the comet's composition
- Detail the comet's physical properties
- Examine the evolution of activity
- Constrain the comet's origin
- Create portraits of two asteroids

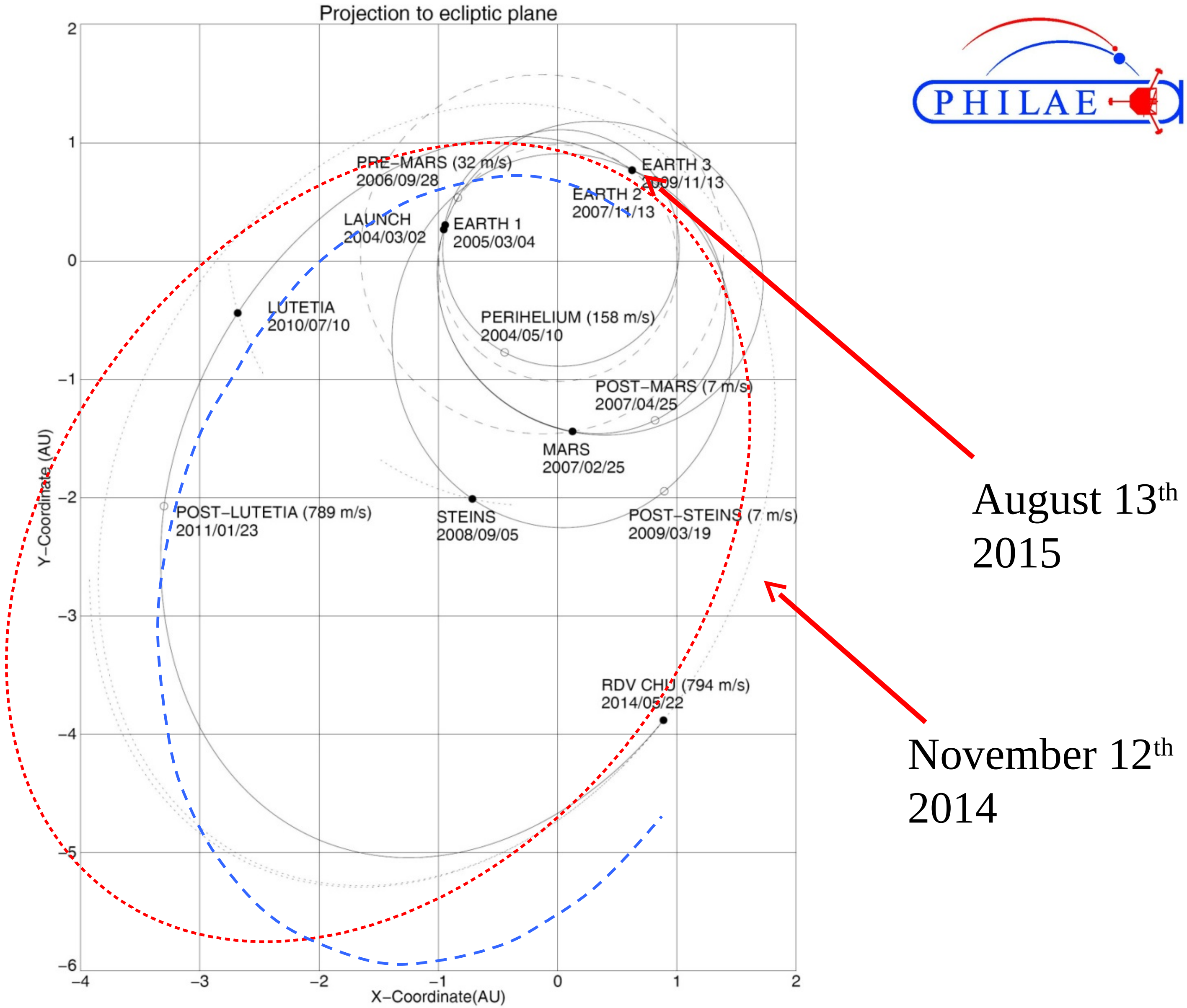
Rosetta

Full suite of in situ and remote sensing instruments (11 total)



hilae (10 instruments)

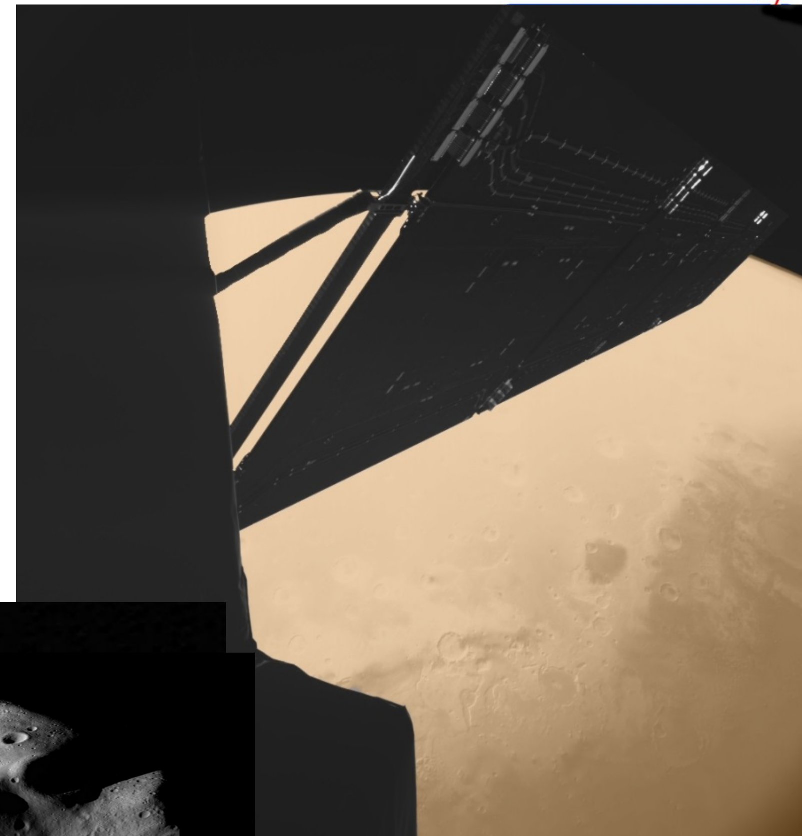




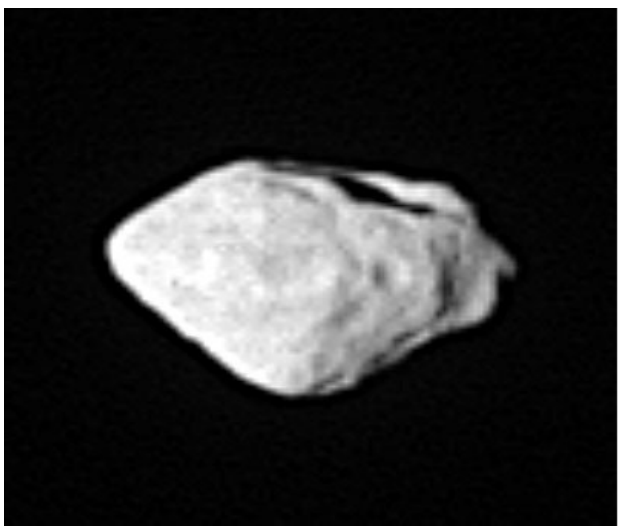
Drawings: ESOC

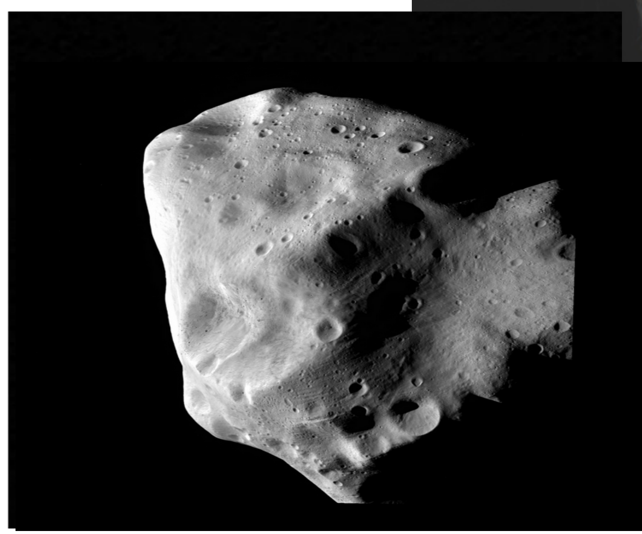
10 years of Cruise

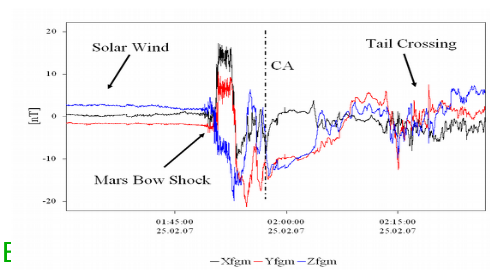
- Mars swingby, February23rd 2007; CA: 250.6 km
- Šteins : September 5th 2008
- Lutetia: July 10th 2010
- Hibernation: Dec 2010 - Mar 2014



Mars as seen by CIVA







E

Images by OSIRIS

(Planned) Landing Scenario

- **Eject from Orbiter**
- **Descent (ballistic)**
- **Stabilization with flywheel**
- ***Activation of compressed gas system (ADS)***
- ***Anchoring***

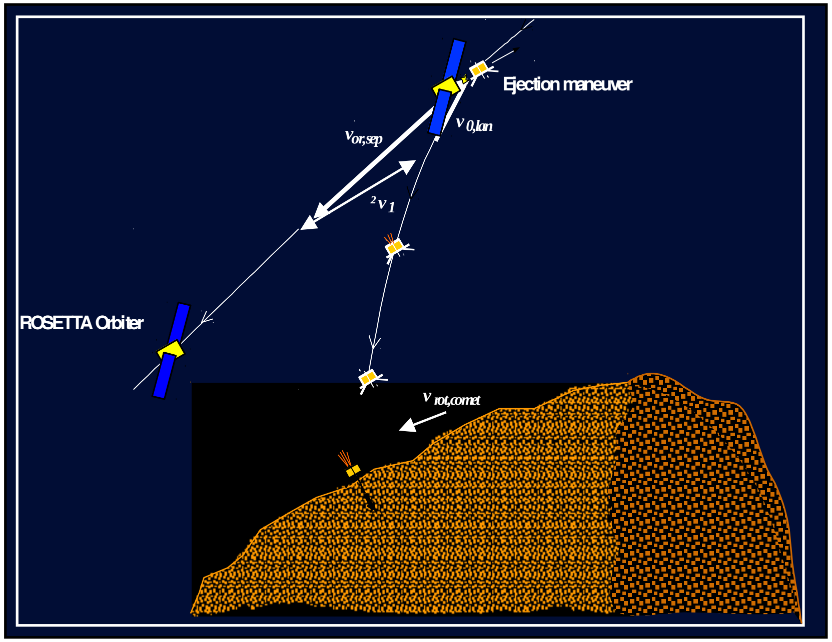


Image: OSIRIS (early July)

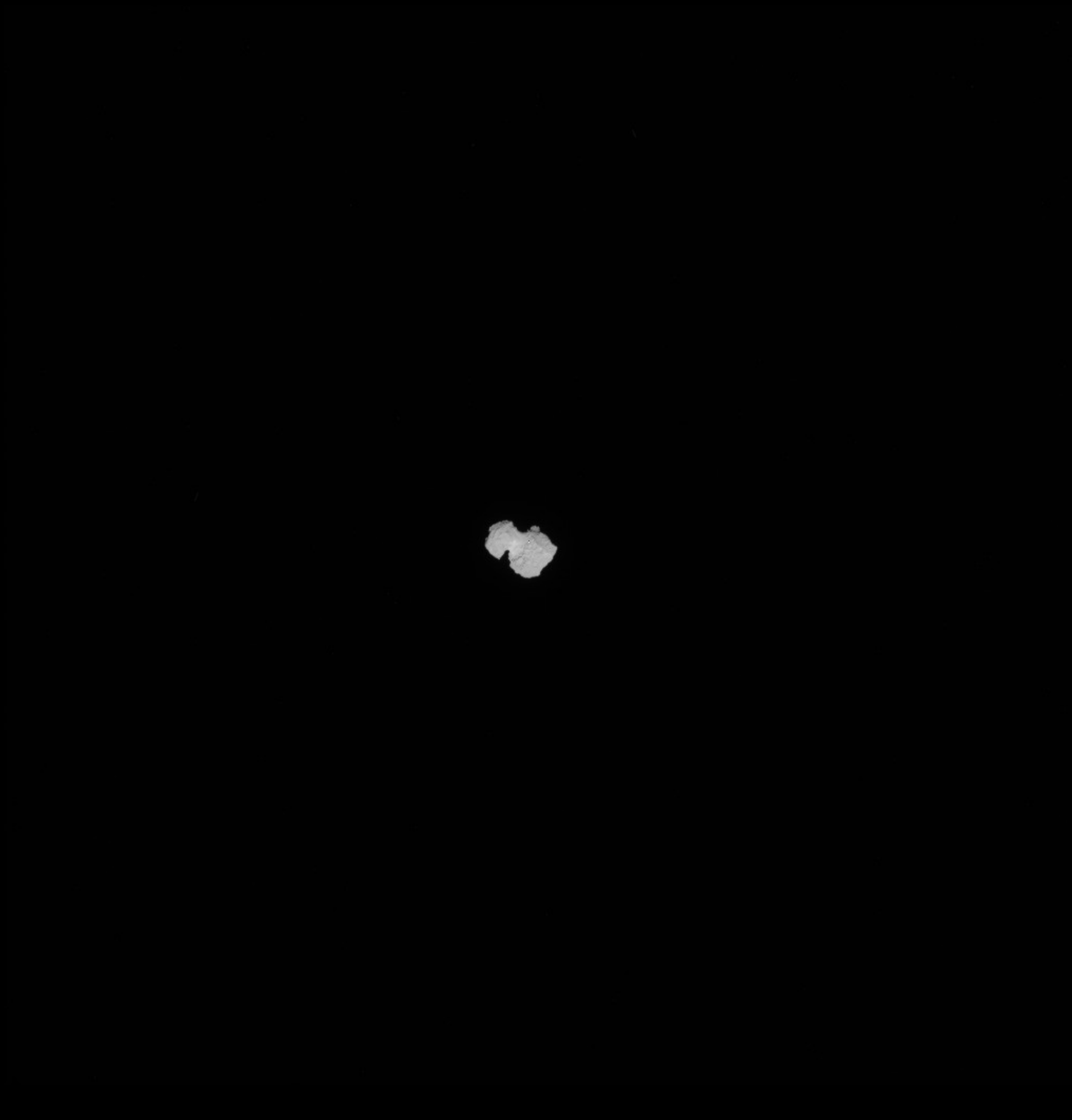


Image: CIVA from 50 km

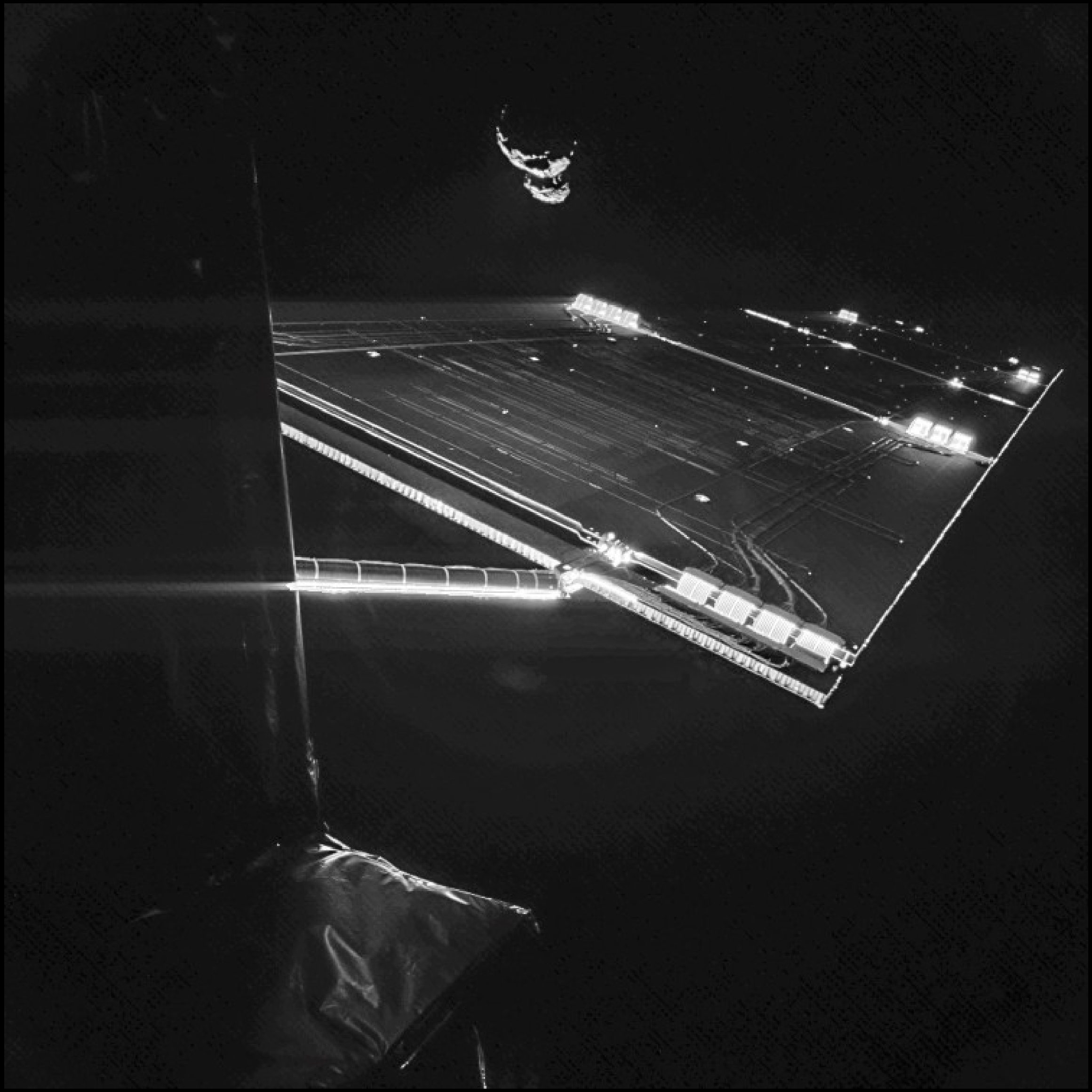
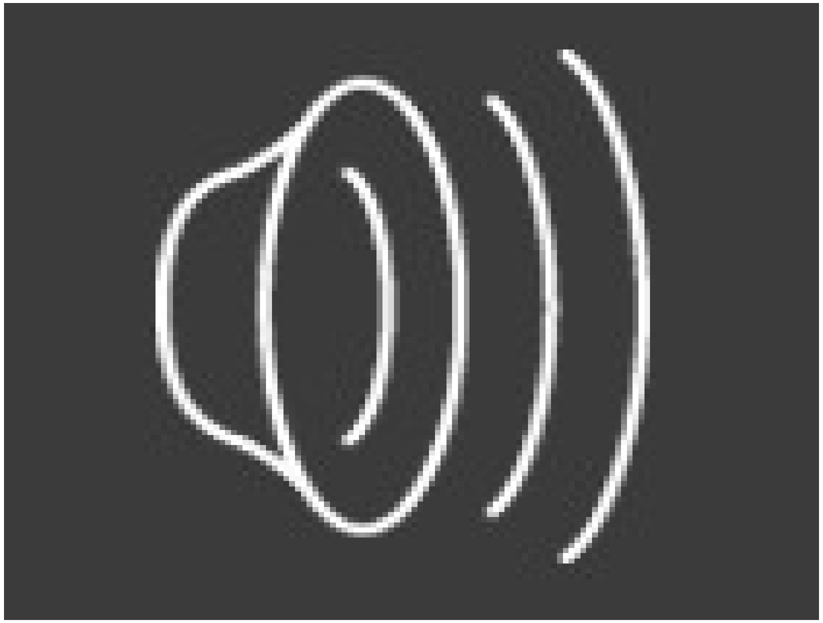
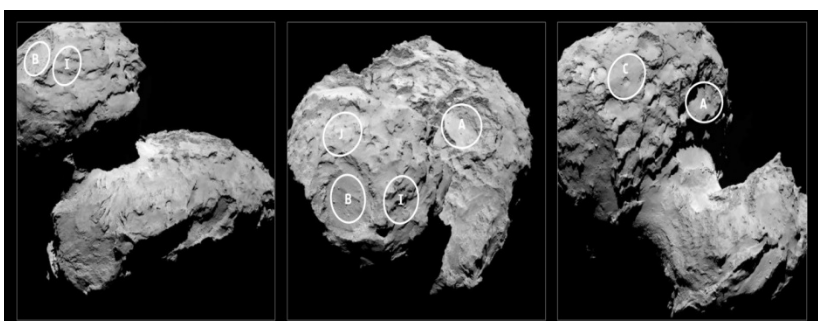
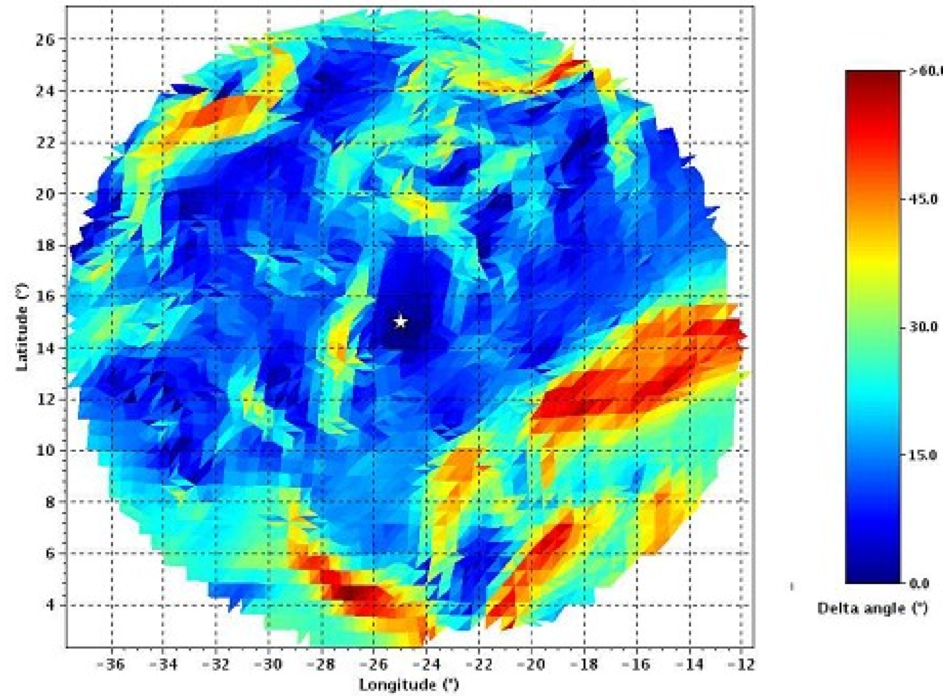


Image: OSIRIS NAC (from 50 km)

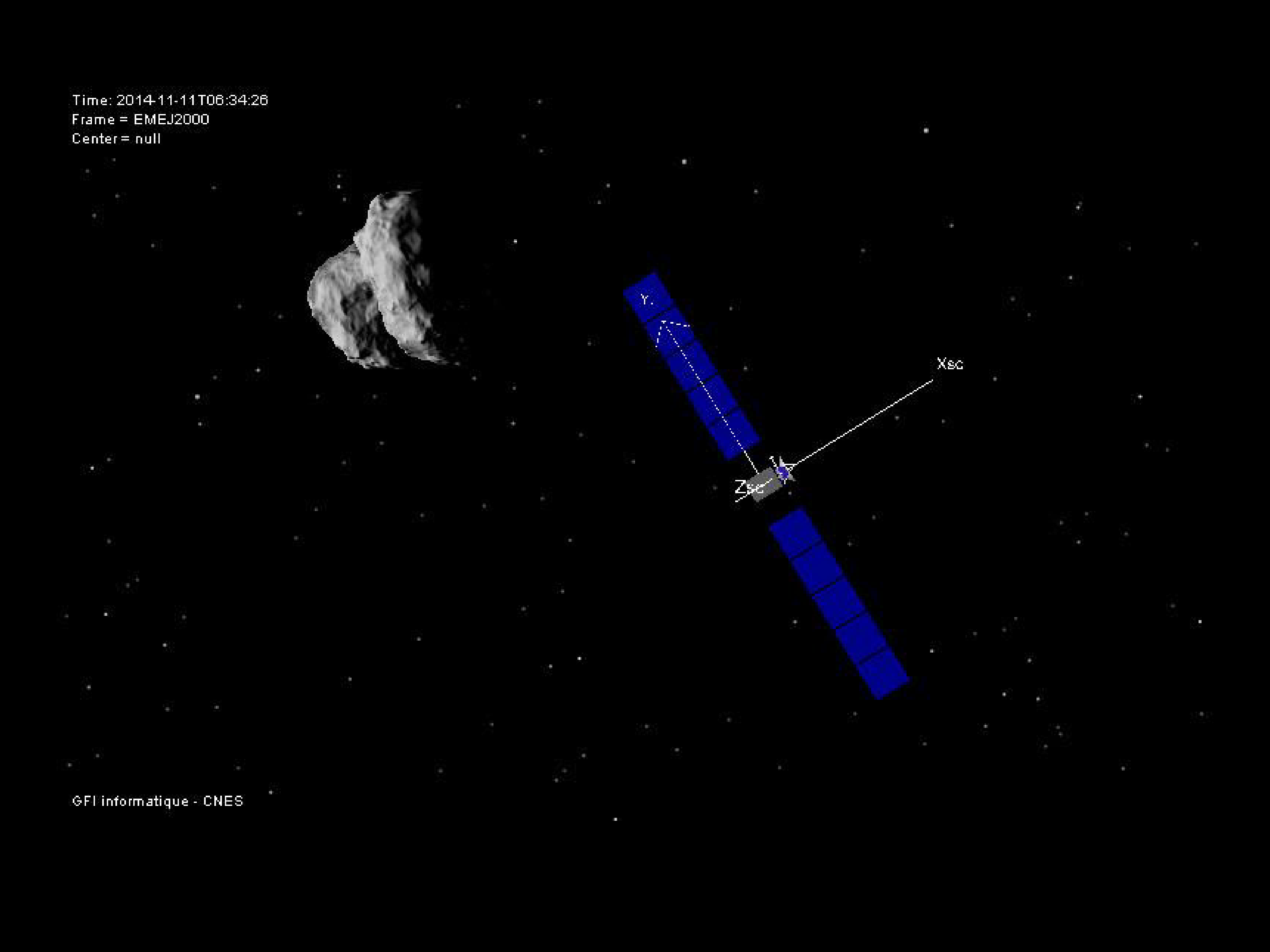
Reminder: our site J, (Agilkia)



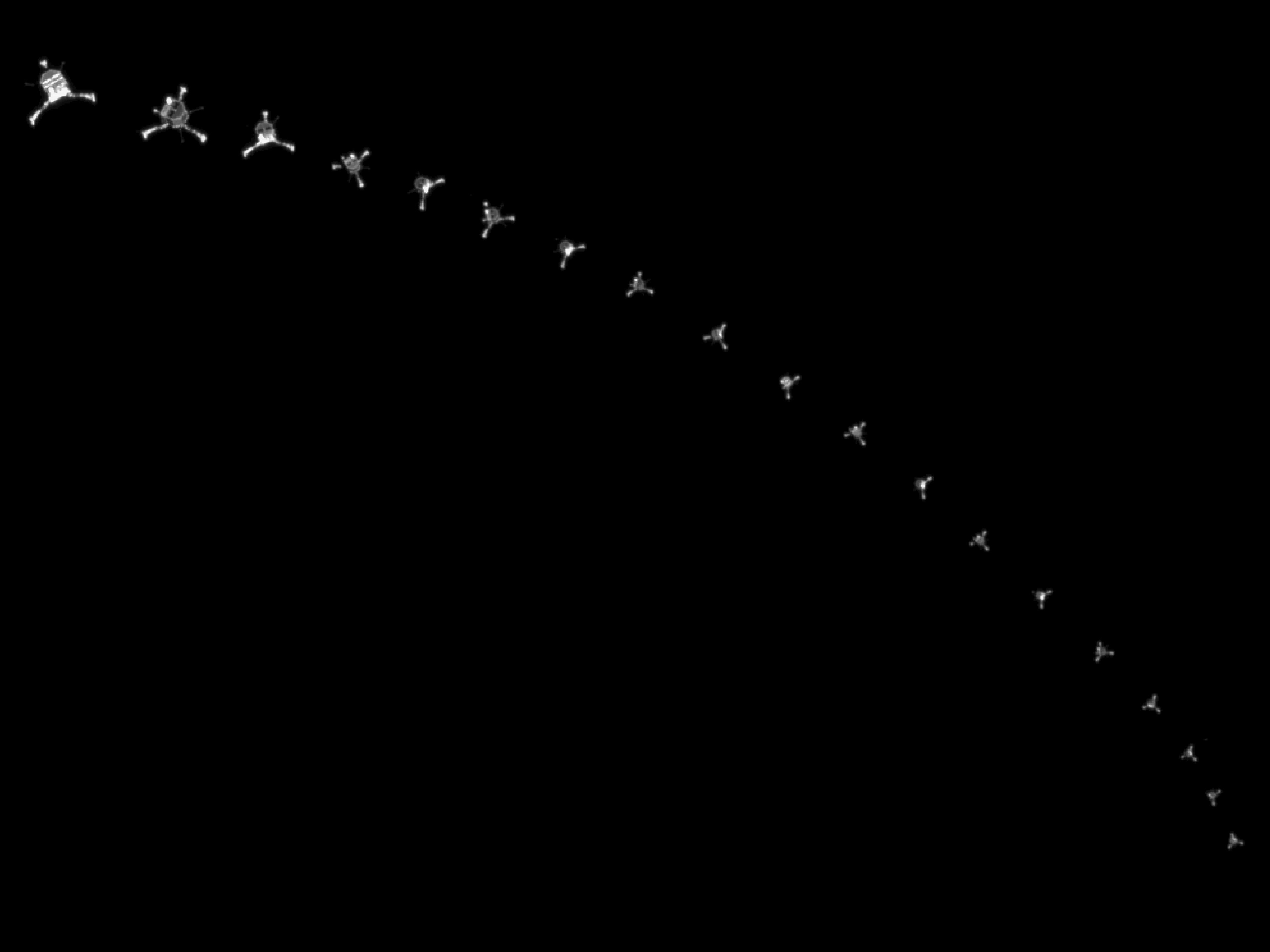


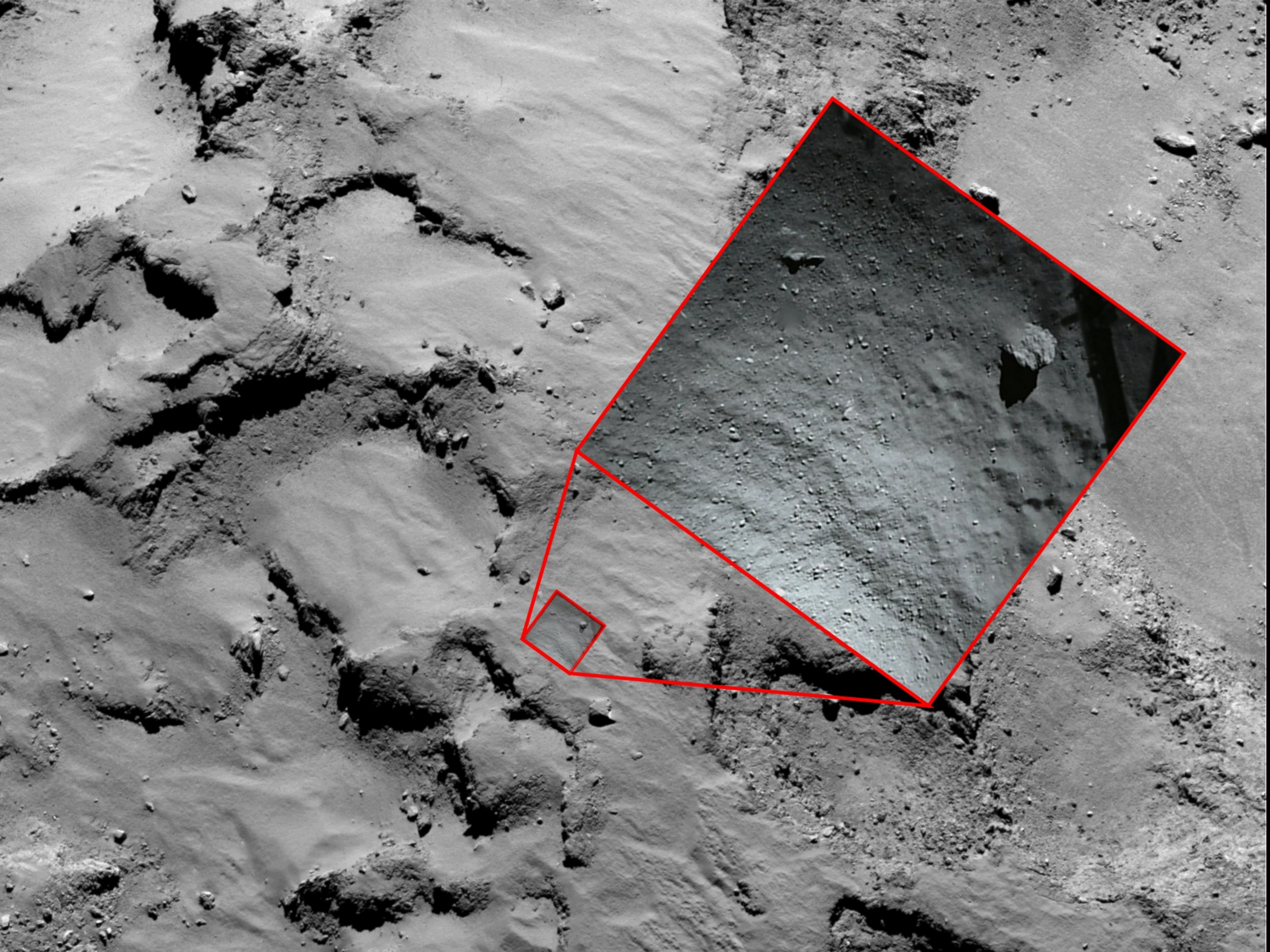


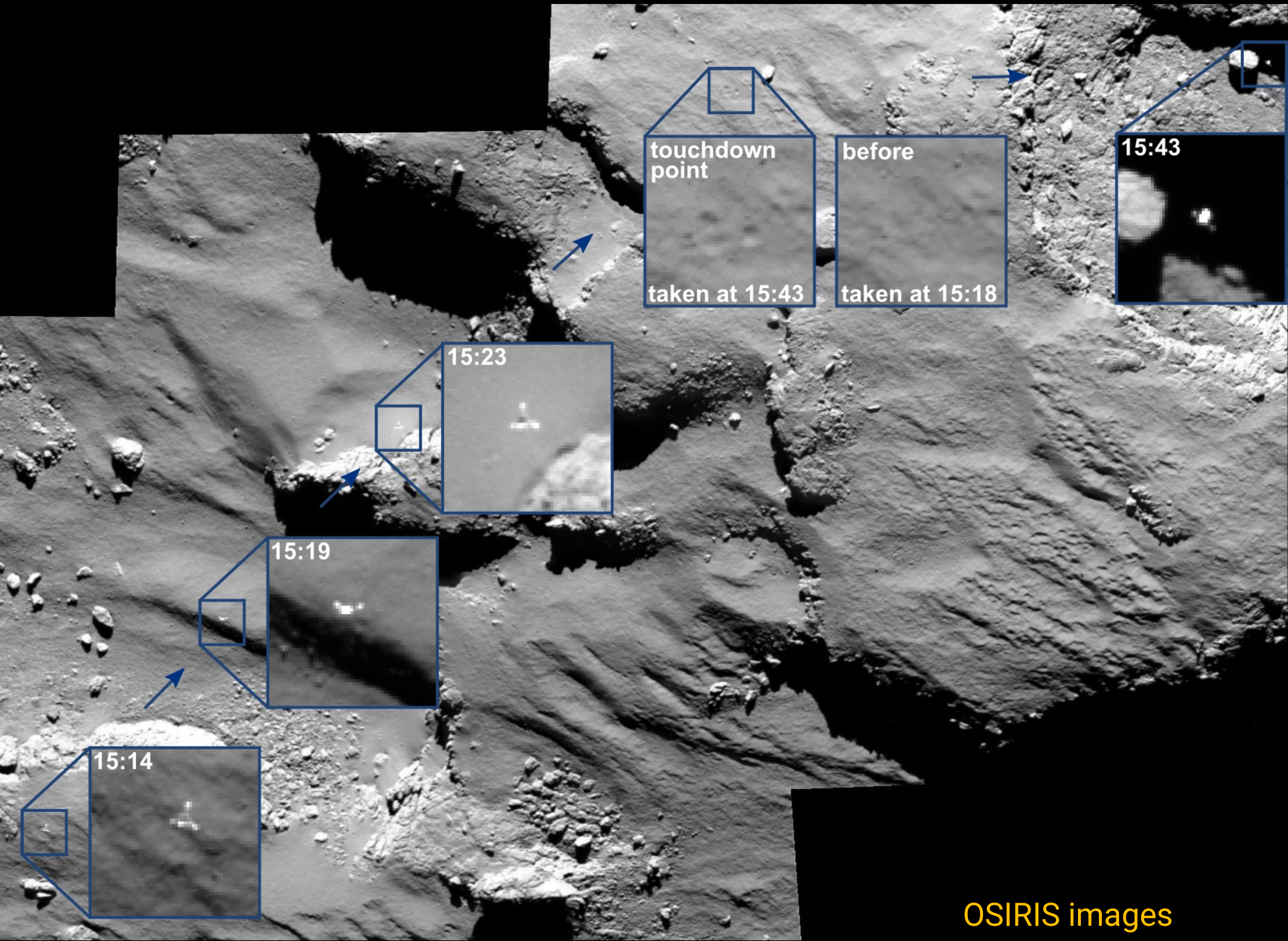
OSIRIS DTM



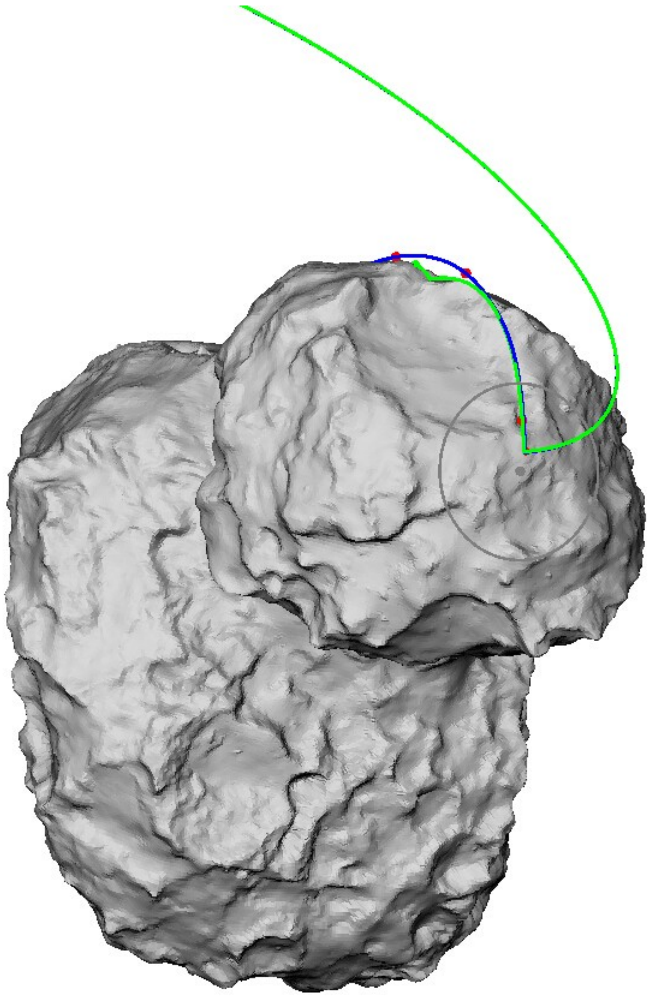
Time: 2014-11-11T06:34:26
Frame = EMEJ2000
Center = null
Y
Xsc
Zsc
GFI informatique - CNES

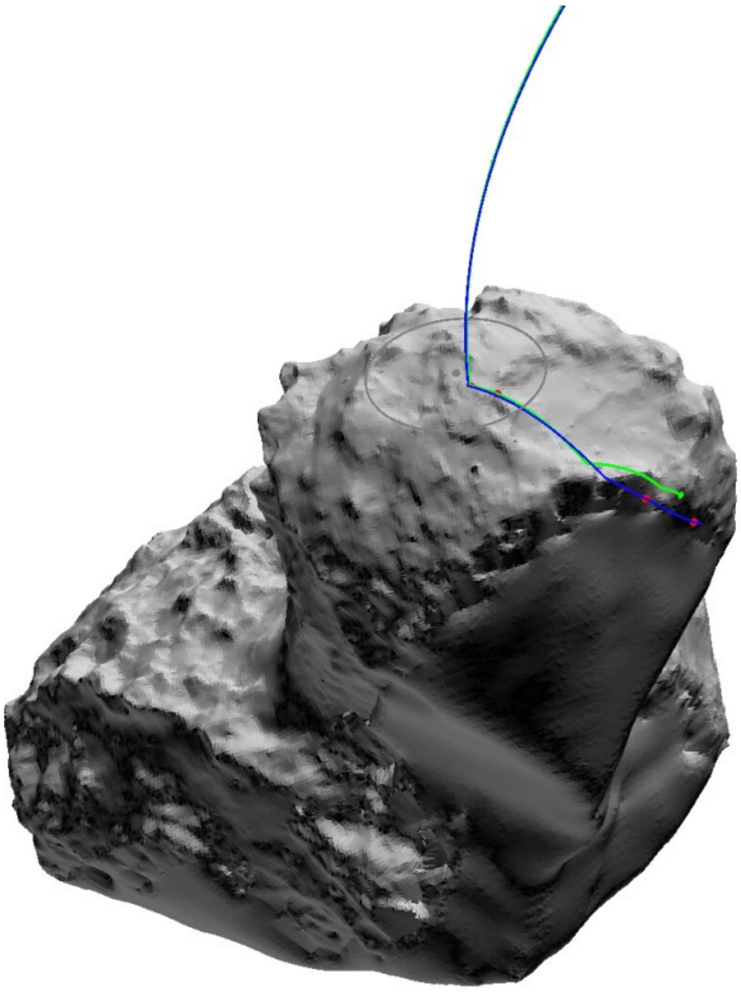




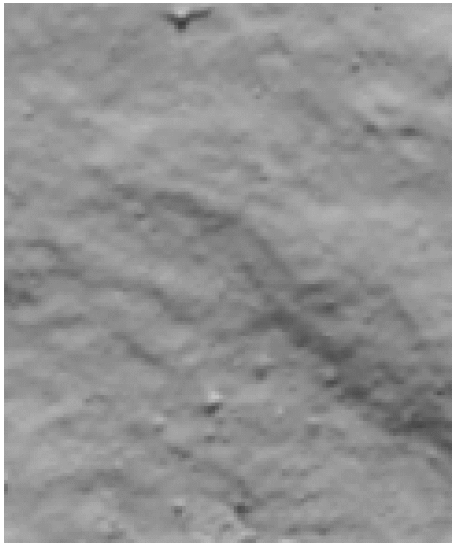

touchdown point
taken at 15:43
before
taken at 15:18
15:43
15:23
15:19
15:14
OSIRIS images

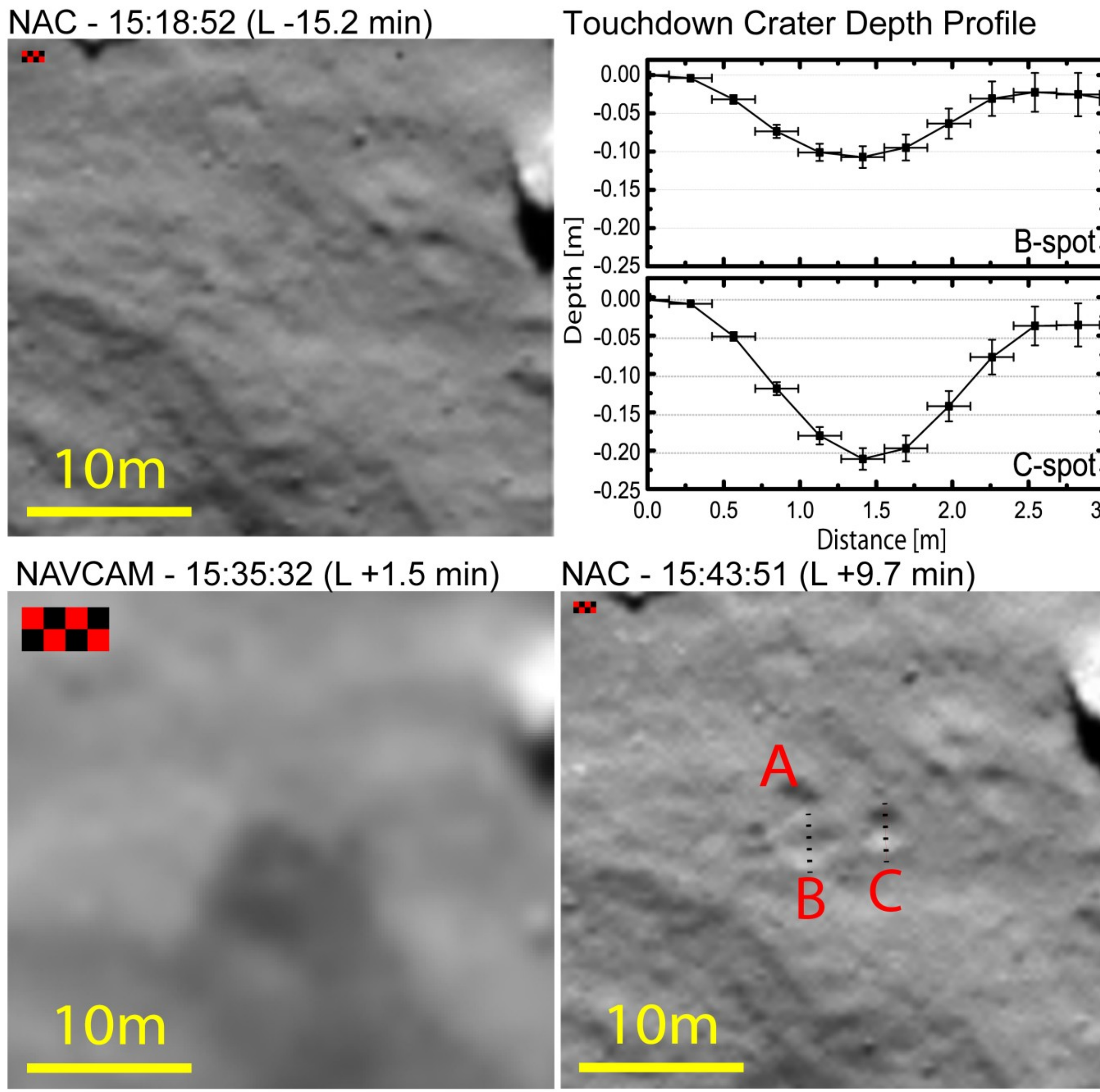
Trajectory after first touch-down

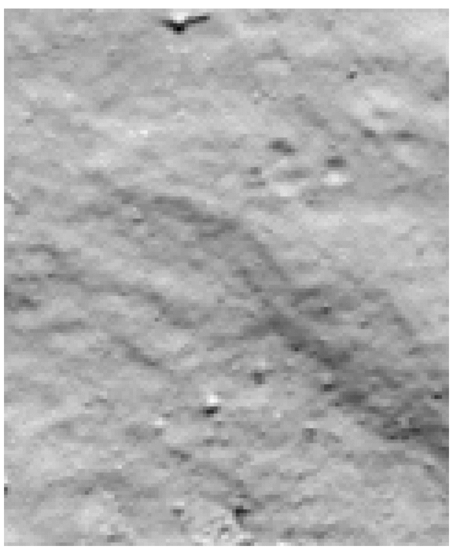




before



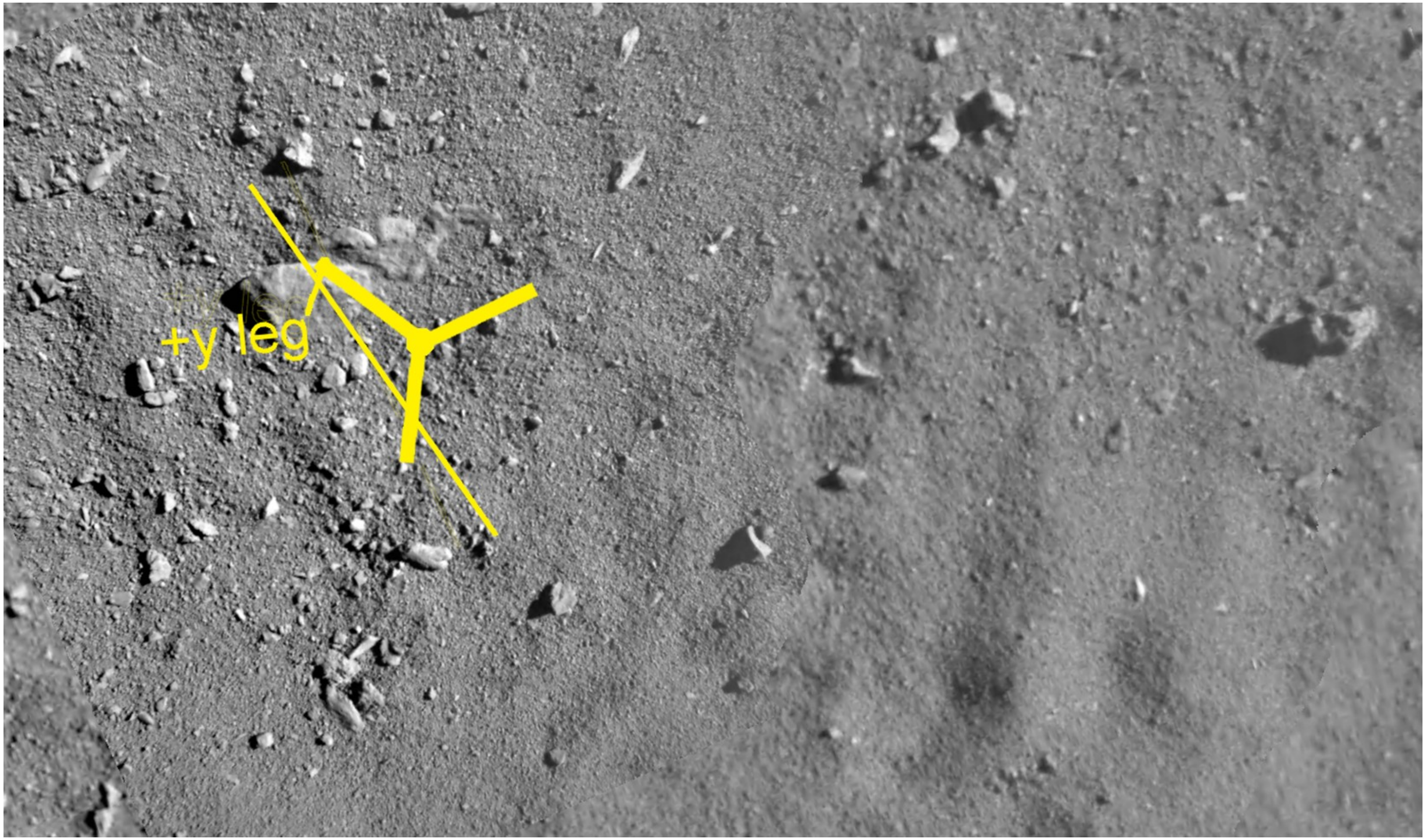




after

Biele et al, *Science*, 2015

Position & attitude at TD1

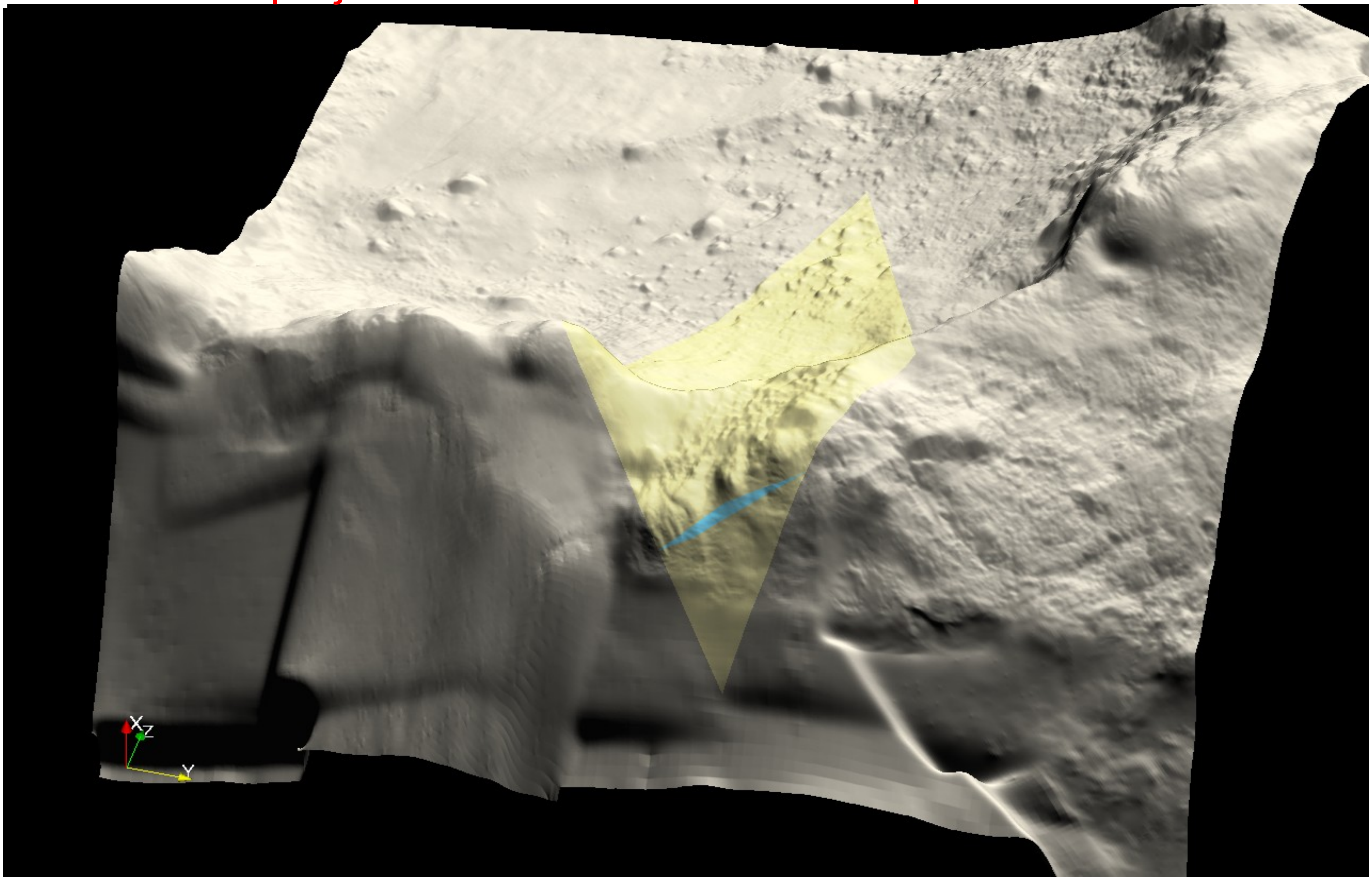


From: Mottola et al.; ROLIS

CIVA panoramic at final TD site

See Bibring *et al.* Science, 2015

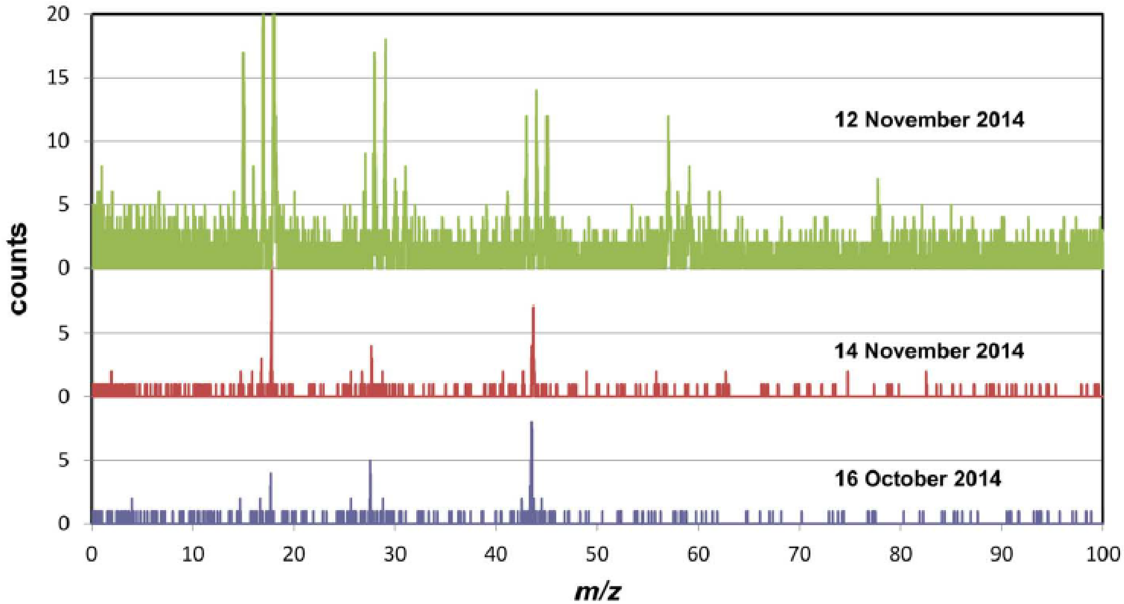
CONSERT's determination of the final landing area, detailed projection on OSIRIS DTM6V7 shape model



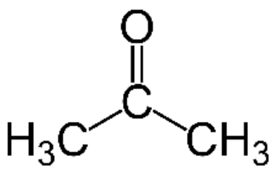
Some Lander results

- Structure of Comet Material in the <1cm scale (ROLIS, CIVA)
- Surface strength and thermal inertia (MUPUS, System)
- Organic componds (COSAC, Ptolemy)
- Comet is non-magnetic (ROMAP)
- Internal structure (CONSERT)

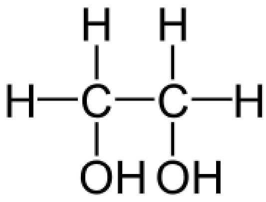
Molecules detected by COSAC



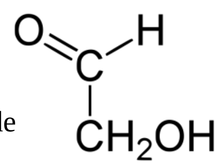
COSAC Mass Spectra
from Goesmann *et al.*, 2015



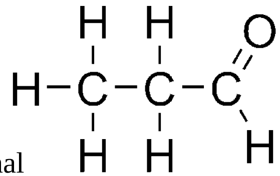
Acetone



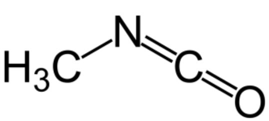
Ethanediol



Glycolaldehyde



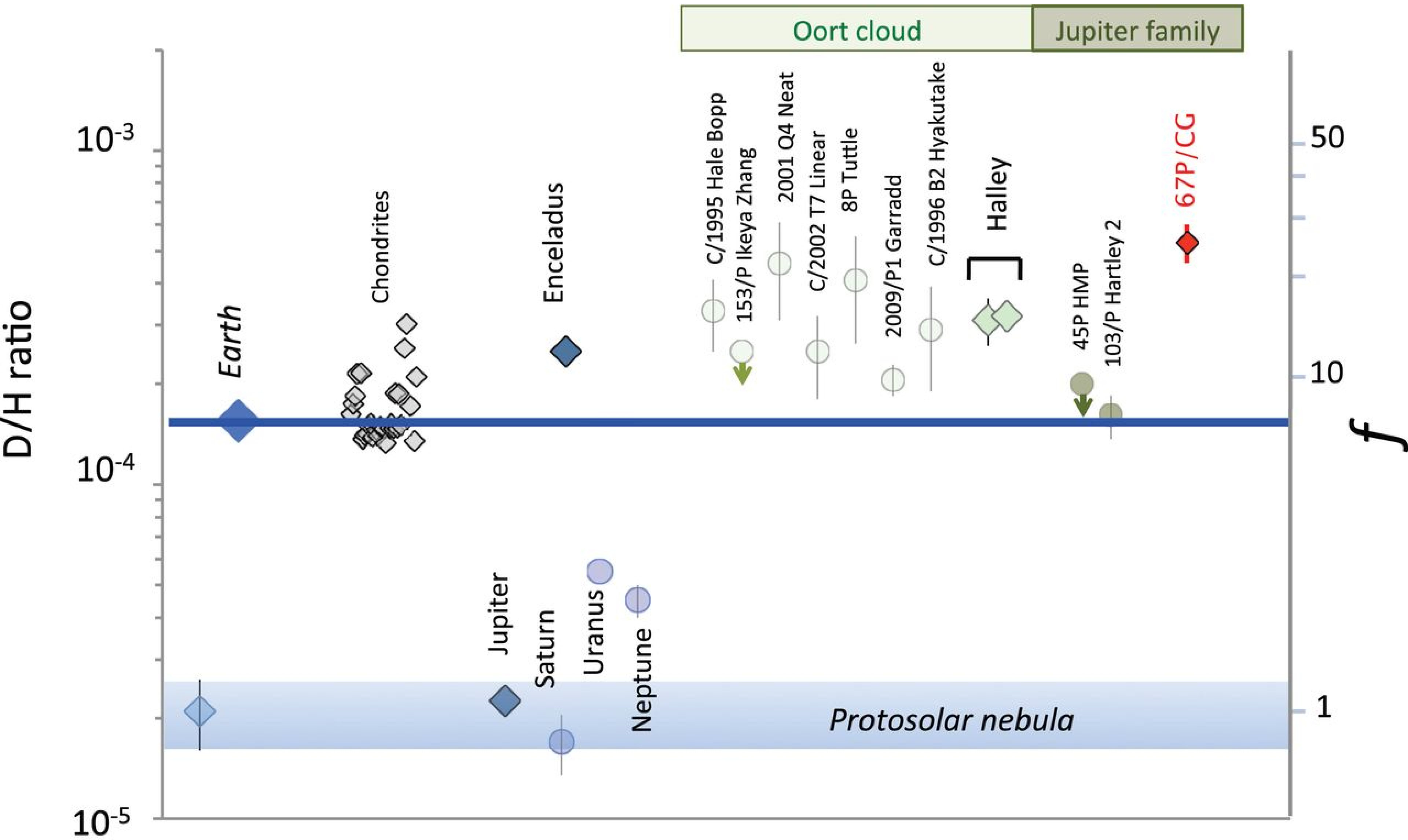
Propanal



Isocyanomethane

Name	Formula
Water	H_2O
Methane	CH_4
Methanenitrile (hydrogen cyanide)	HCN
Carbon monoxide	CO
Methylamine	CH_3NH_2
Ethanenitrile (acetonitrile)	CH_3CN
Isocyanic acid	HNCO
Ethanal (acetaldehyde)	CH_3CHO
Methanamide (formamide)	$HCONH_2$
Ethylamine	$C_2H_5NH_2$
Isocyanomethane (methyl isocyanate)	CH_3NCO
Propanone (acetone)	CH_3COCH_3
Propanal (propionaldehyde)	C_2H_5CHO
Ethanamide (acetamide)	CH_3CONH_2
2-Hydroxyethanal (glycolaldehyde)	CH_2OHCHO
1,2-Ethanediol (ethylene glycol)	$CH_2(OH)CH_2(OH)$

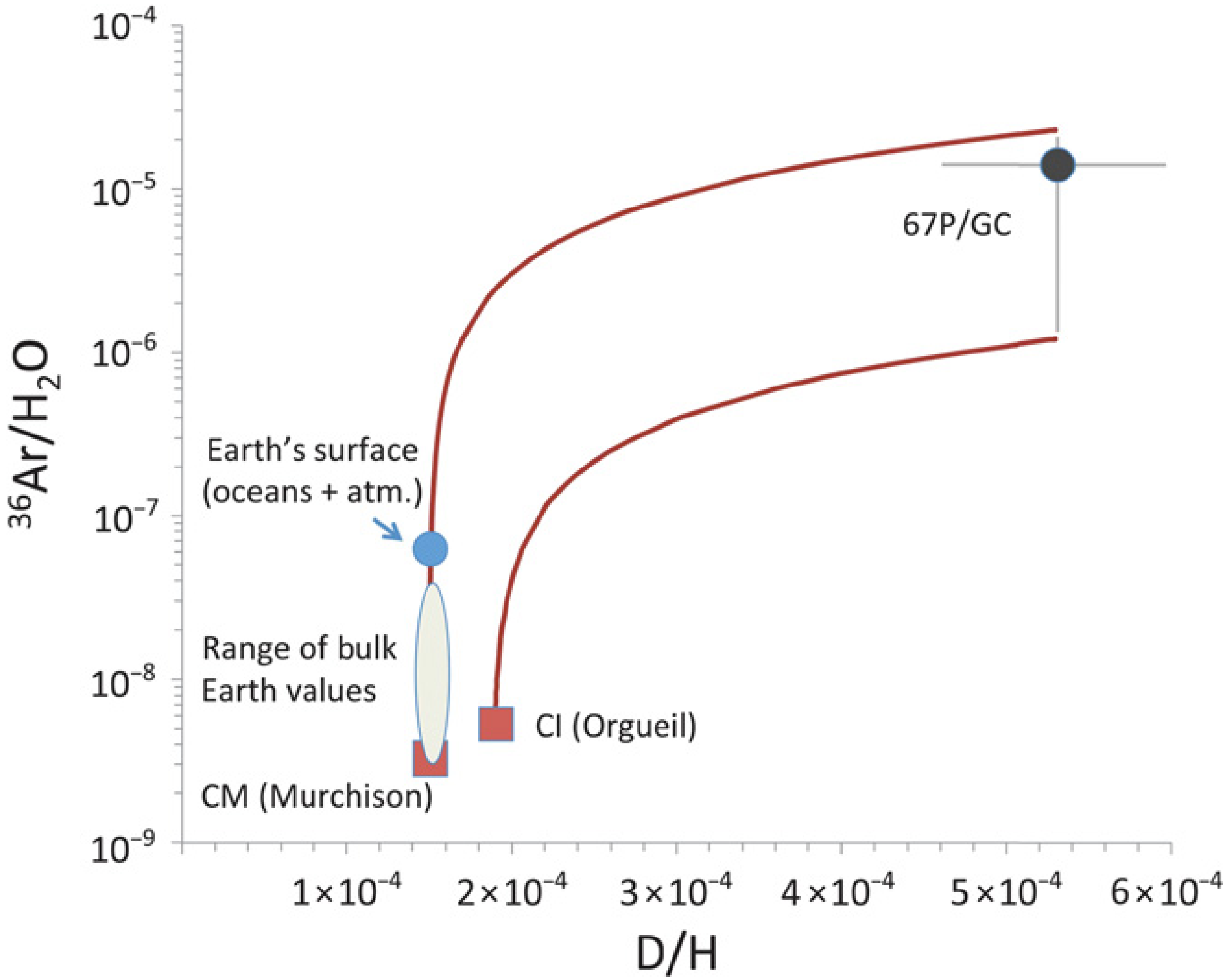
Fig 3. D/H in various Solar System environments.



Kathrin Altwegg et al. Vol. 347 no. 6220 DOI: 10.1126/science.1261952

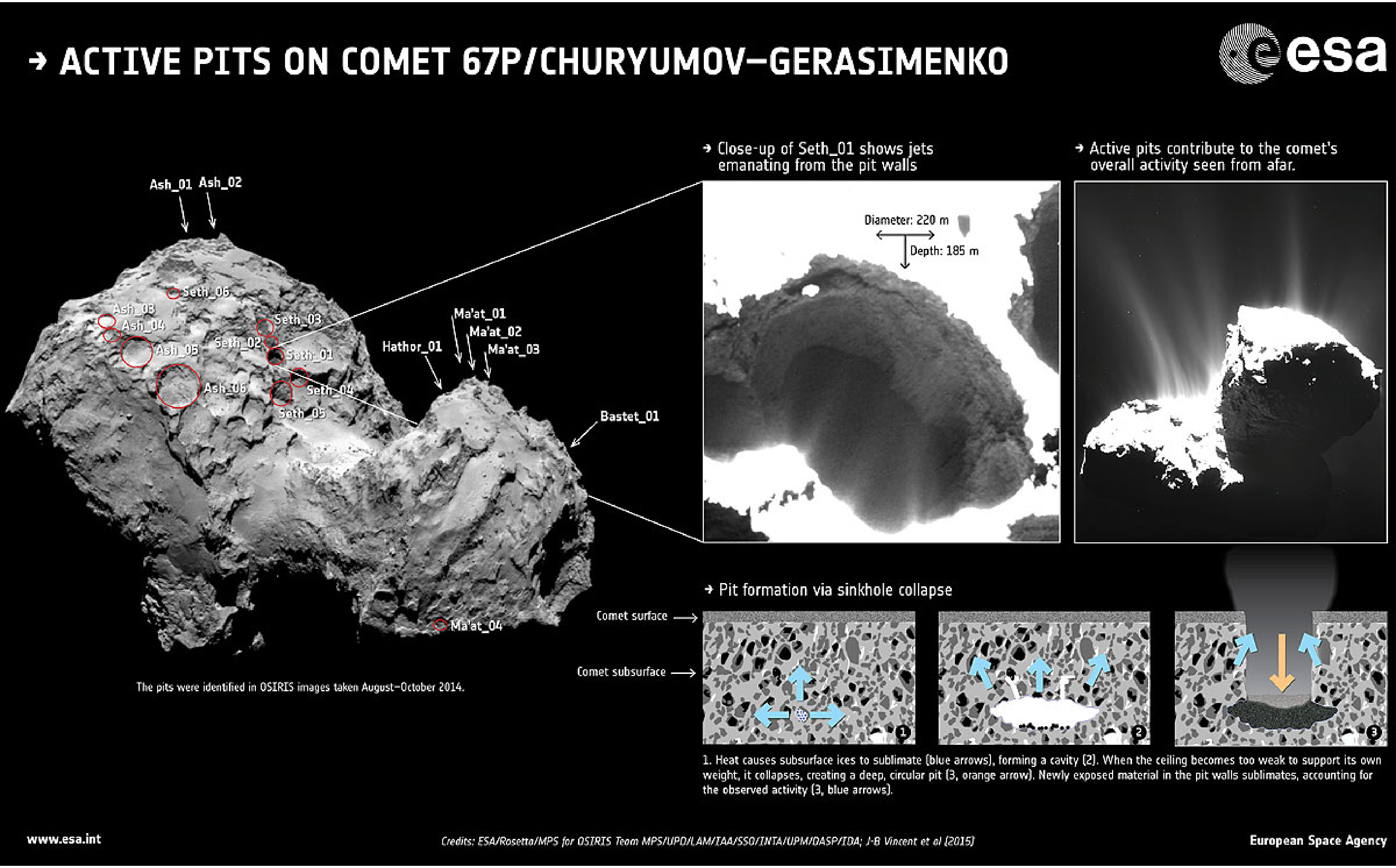
Published by AAAS

Fig. 3 D/H versus 36Ar/H2O mixing of 67P/CG-like and asteroidal materials.



Hans Balsiger et al. Sci Adv 2015;1:e1500377

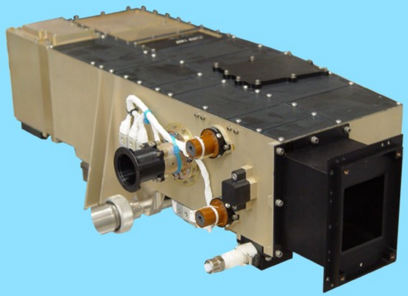
Short outbursts in activity near perihelion



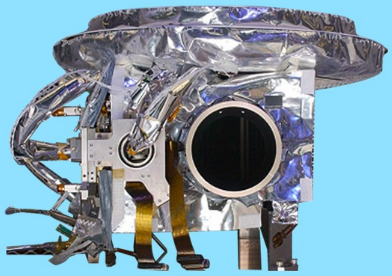
→ ACTIVE PITS ON COMET 67P/CHURYUMOV–GERASIMENKO
esa
Ash_01
Ash_02
Seth_06
Ash_03
Ash_04
Ash_05
Ash_06
Seth_03
Seth_02
Seth_01
Seth_04
Seth_05
Hathor_01
Ma'at_01
Ma'at_02
Ma'at_03
Bastet_01
Ma'at_04
The pits were identified in OSIRIS images taken August–October 2014.
→ Close-up of Seth_01 shows jets emanating from the pit walls
Diameter: 220 m
Depth: 185 m
→ Active pits contribute to the comet's overall activity seen from afar.
→ Pit formation via sinkhole collapse
Comet surface
Comet subsurface
1
2
3
1. Heat causes subsurface ices to sublimate (blue arrows), forming a cavity (2). When the ceiling becomes too weak to support its own weight, it collapses, creating a deep, circular pit (3, orange arrow). Newly exposed material in the pit walls sublimates, accounting for the observed activity (3, blue arrows).
www.esa.int
Credits: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA; J-B Vincent et al (2015)
European Space Agency

BACKUP

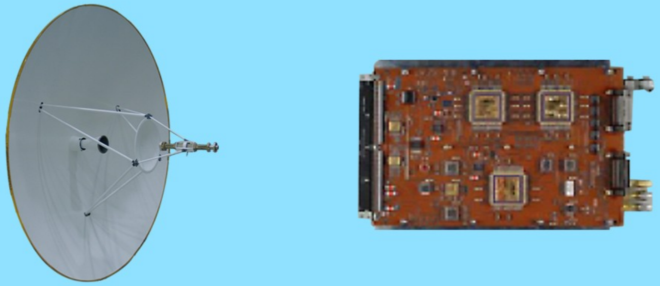
Advanced Science Instruments



Alice UV Spectrograph, 46.5-188 nm,
Mass 4.15 kg, Power 3.6 W

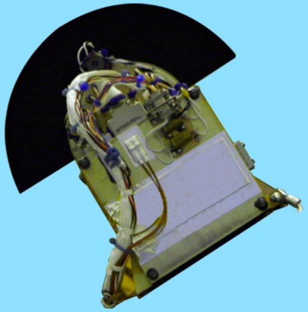


Ralph Visible Color Imager (MVIC)
and IR Spectral Imager (LEISA),
Mass 10.67 kg, Power 6.74 W

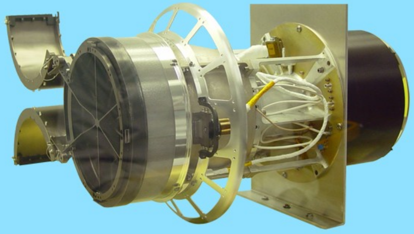


Radio Experiment (REX), Antenna (2.1 m)
+ Processing Card (0.1 kg, 2.1 W)

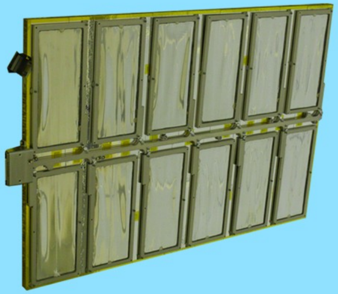
Long Range Reconnaissance Imager
(LORRI), Panchromatic Visible Imager,
Mass 9.03 kg, Power 4.6 W



Pluto Energetic Particle Spectrometer
Science Investigation (PEPSSI),
Mass 1.48 kg, Power 2.45 W



Solar Wind at Pluto (SWAP),
Mass 3.3 kg, Power 2.84 W



Venetia Burney Student Dust Counter
(VB-SDC), Mass 1.69 kg, Power 6.4 W

Totals: Mass < 30 kg, Power < 30 W

New Horizons Science Objectives at Pluto

Group 1 Objectives: REQUIRED	
Specified by NASA	**Added and ranked by New Horizons Science Team**
Characterize the global geology and morphology of Pluto and Charon	None
Map surface composition of Pluto and Charon	
Characterize the neutral atmosphere of Pluto and its escape rate	

Group 2 Objectives: STRONGLY DESIRED	
Specified by NASA	**Added and ranked by New Horizons Science Team**
Characterize the time variability of Pluto's surface and atmosphere	Composition of dark surfaces on Pluto
Image Pluto and Charon in Stereo	"Far-side" imaging of Pluto and Charon
Map the terminators of Pluto and Charon with high resolution	"Far-side" color and composition of Pluto and Charon
Characterize Pluto's ionosphere and solar wind interaction	High resolution imaging of Nix, Hydra, Kerberos, Styx
Search for neutral species including H, H2, HCN, and CxHy, and other hydrocarbons and nitriles in Pluto's upper atmosphere	Composition of Nix, Hydra, Kerberos, Styx
Search for an atmosphere around Charon	Shapes of Nix, Hydra, Kerberos, Styx
Determine bolometric Bond albedos for Pluto and Charon	
Map the surface temperatures of Pluto and Charon	

Group 3 Objectives: DESIRED	
Specified by NASA	**Added and ranked by New Horizons Science Team**
Characterize the energetic particle environment of Pluto and Charon	Surface microphysics of Pluto and Charon
Refine bulk parameters (radii, masses, densities) and orbits of Pluto & Charon	Measure the surface temperatures of Nix and Hydra
Search for magnetic fields of Pluto and Charon	Measure the phase curve of Nix and Hydra
Search for additional satellites and rings	Image Nix and Hydra in stereo
	Refine orbits of Nix, Hydra, Kerberos, Styx

- **New Horizons expects to accomplish *all* the above objectives with the *exception* of measuring magnetic fields directly**

Science Highlights in Encounter Year

2015

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
AP1			AP2			AP3 / DP1	DP2		DP3		

NEP

Near Encounter Phase (NEP): P-1 to P+1 day

AP3 and DP1 Activities, Plus:

Best Geologic, Color, & IR/Comp Maps
Phase Function: Low, Mid, & High Phase Images
Atm Escape & Structure: Lyman-Alpha maps
Atm Comp: Airglow
Atm Comp & Structure: Occs & Airglow

Surface Comp: UV Reflectance
High-res Geologic, Color, and Comp Images
Temperatures: Surface IR and Radiometry
Stereo, Topography, Shape & Radii: images
Trajectory & Masses: Doppler Tracking

GROUP 1 (Required Science Objectives) In Bold Italic

Approach Phase 3 (AP3): P-21 to P-1 day

AP2 Activities, Plus:

Atm. Escape: pickup ions & bow Shock
Surface Composition Variability
Atmospheric Variability
Clouds/Haze/winds from Imaging
Geologic, Color & Composition Maps
Retargetables
EPO

Departure Phase 1 (DP1): P+1 to P+21 day

DP2 Activities, Plus:

Atm Escape: pickup ions & Magnetotail
Phase Function: Hi-phase Pan & Color Photometry
Surf Comp/Temp: High-phase IR Images
High-phase Geologic Maps
Retargetables
EPO

Approach Phase 2 (AP2): P-100 to P-21 day

AP1 Activities, Plus:

Surface Color Variability
Satellite & Ring Search

Departure Phase 2 (DP2): P+21 to P+100 day

Atm Escape: Ambient Plasma
Ring & Satellite Search
L4/L5 Search

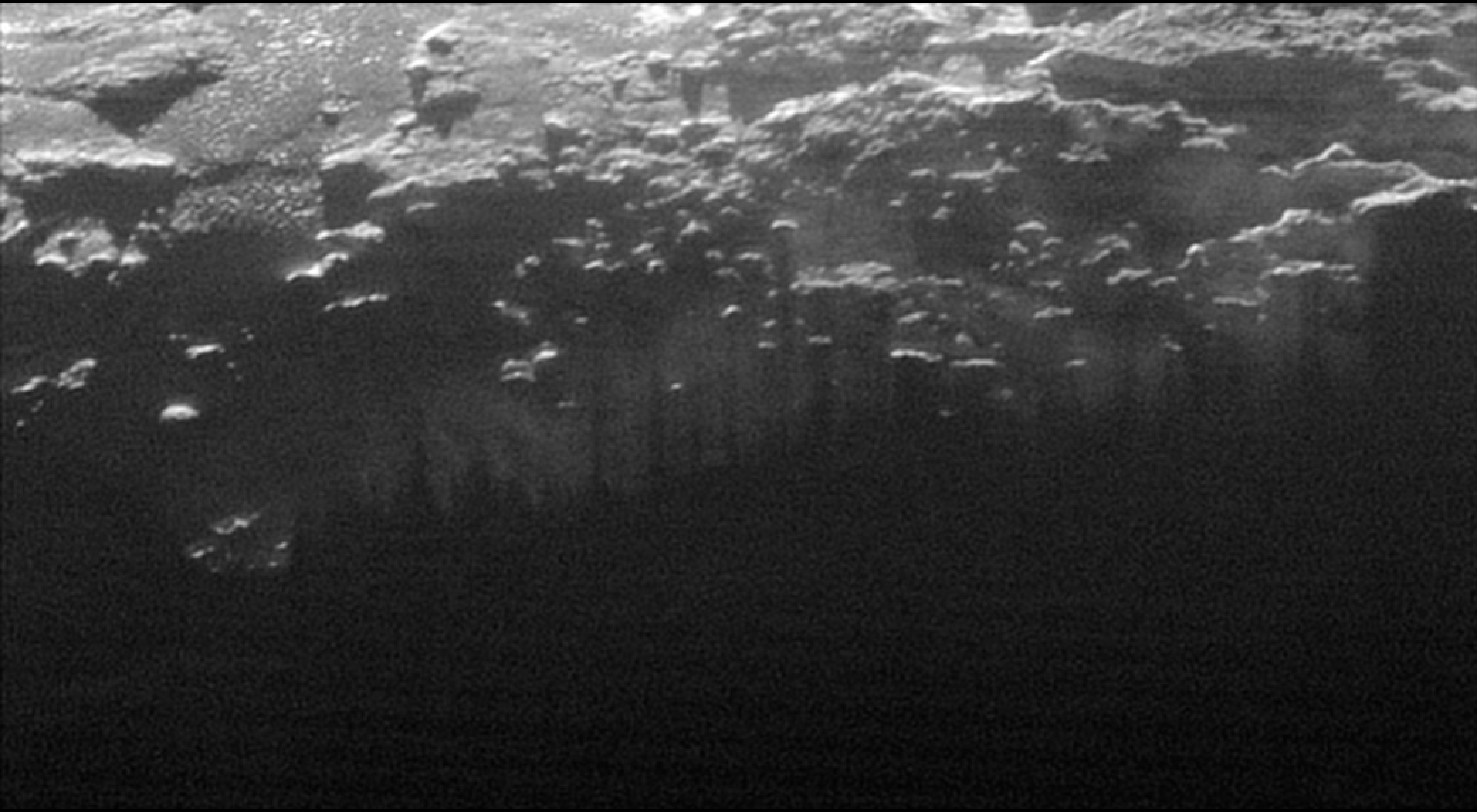
Approach Phase1 (AP1): P+180 to P+100 day

Atm Escape: Ambient Plasma
OpNav/Orbits/Masses
Surface Albedo Variability

Departure Phase 3 (DP3): P+100 to P+180 day

Atm Escape: Ambient Plasma
Interplanetary Dust

Haze Shadows on Pluto



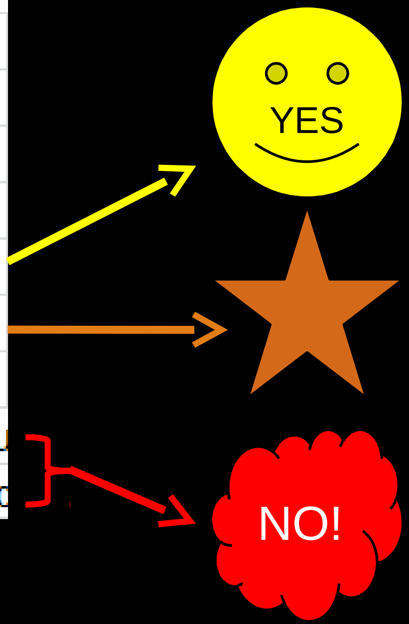
Independence Day Surprise

July 4, 2015:

Round Trip Light Time (RTLT) = 8hrs 49min 03sec

One Way Light Time (OWLT) = 4hrs 24min 31sec

PS-H	Passive Spin Hiberna
PS-N	Passive Spin Normal
PS-TCM	Passive Spin TCM
AS-N	Active Spin Normal
AS-TCM	Active Spin TCM
3A-N	3 Axis Normal
3A-E	3 Axis Encounter
3A-TCM	3 Axis TCM
AS-SA	Active Spin Sun Acqu
AS-EA	Active Spin Earth Acc



Autonomy subsystem: monitors spacecraft and reacts to any unexpected state
-In all modes except 3A-E, it will put spacecraft into safe mode and point to Earth
-In 3A-E, it corrects fault as best it can and continues with science.

If Everything Went As Planned…

July 3: Load 9-day Flyby Commands to Backup Computer

July 4: Load 9-day Flyby Commands to Main Computer

July 7: 12:24pm Start 9-day Flyby, enter Encounter Mode

July 14: Closest Approach of Pluto System

July 16: End 9-day Flyby, exit Encounter Mode

But Things Didn't Go As Planned…

July 4: Entered Safe Mode – too many instructions sent to Main Computer

July 5: Exit Safe Mode

July 6: Switched back to Main computer, load 9-day Flyby commands

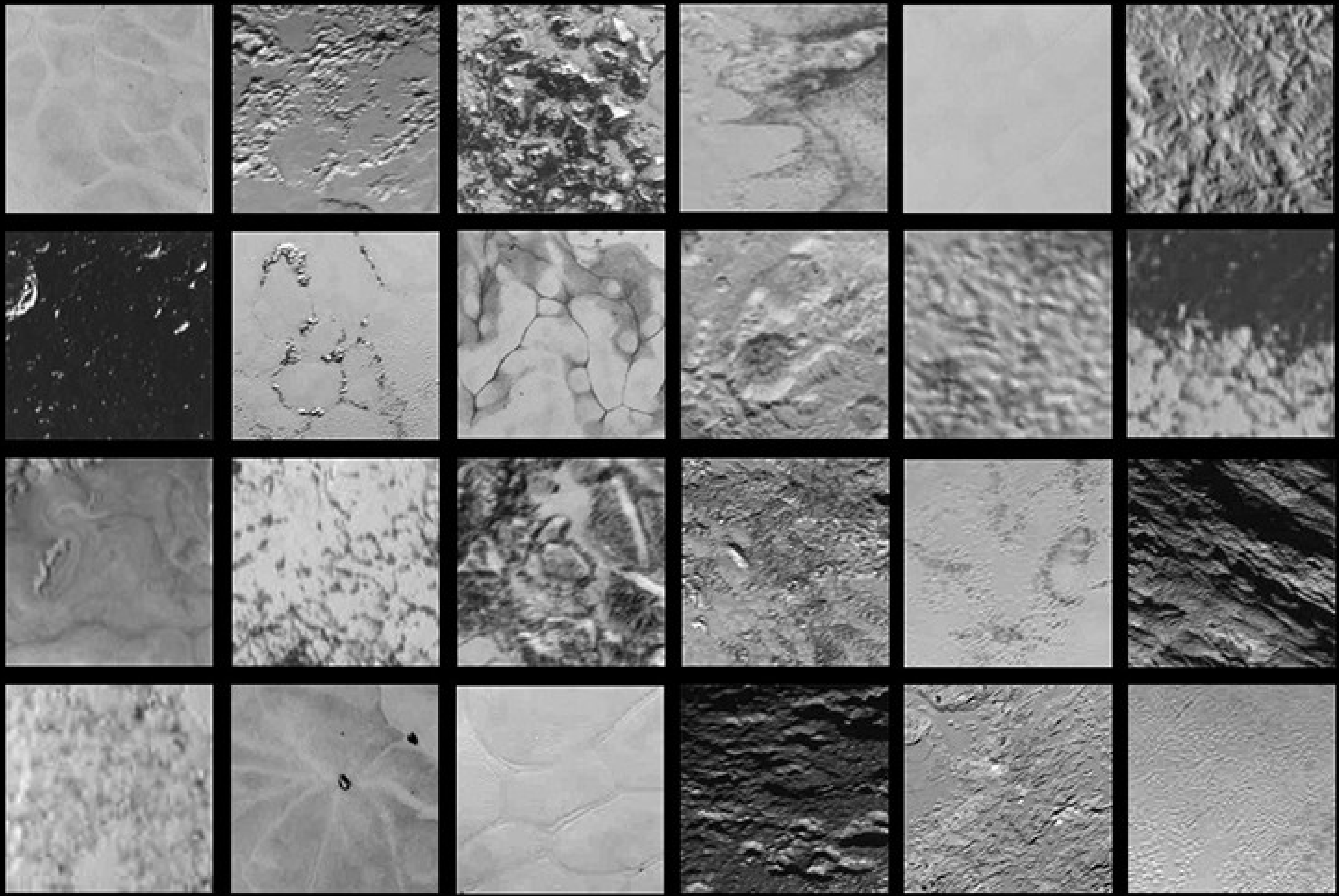
July 7: 12:24pm Start 9-day Flyby, enter Encounter Mode

July 14: Closest Approach of Pluto System

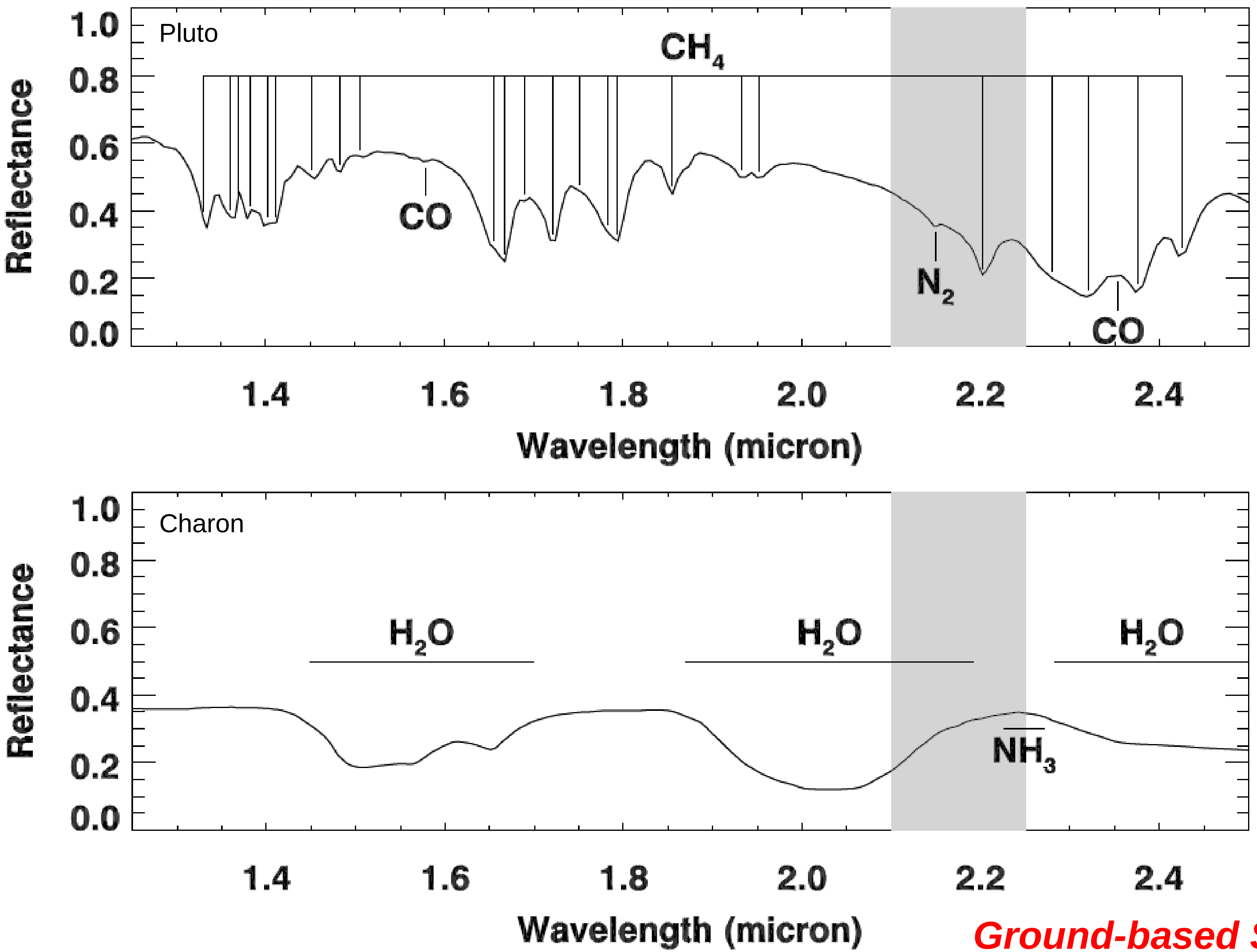
July 16: End 9-day Flyby, exit Encounter Mode

But in the end, this is what happened…

Pluto's Incredible Terrain Diversity

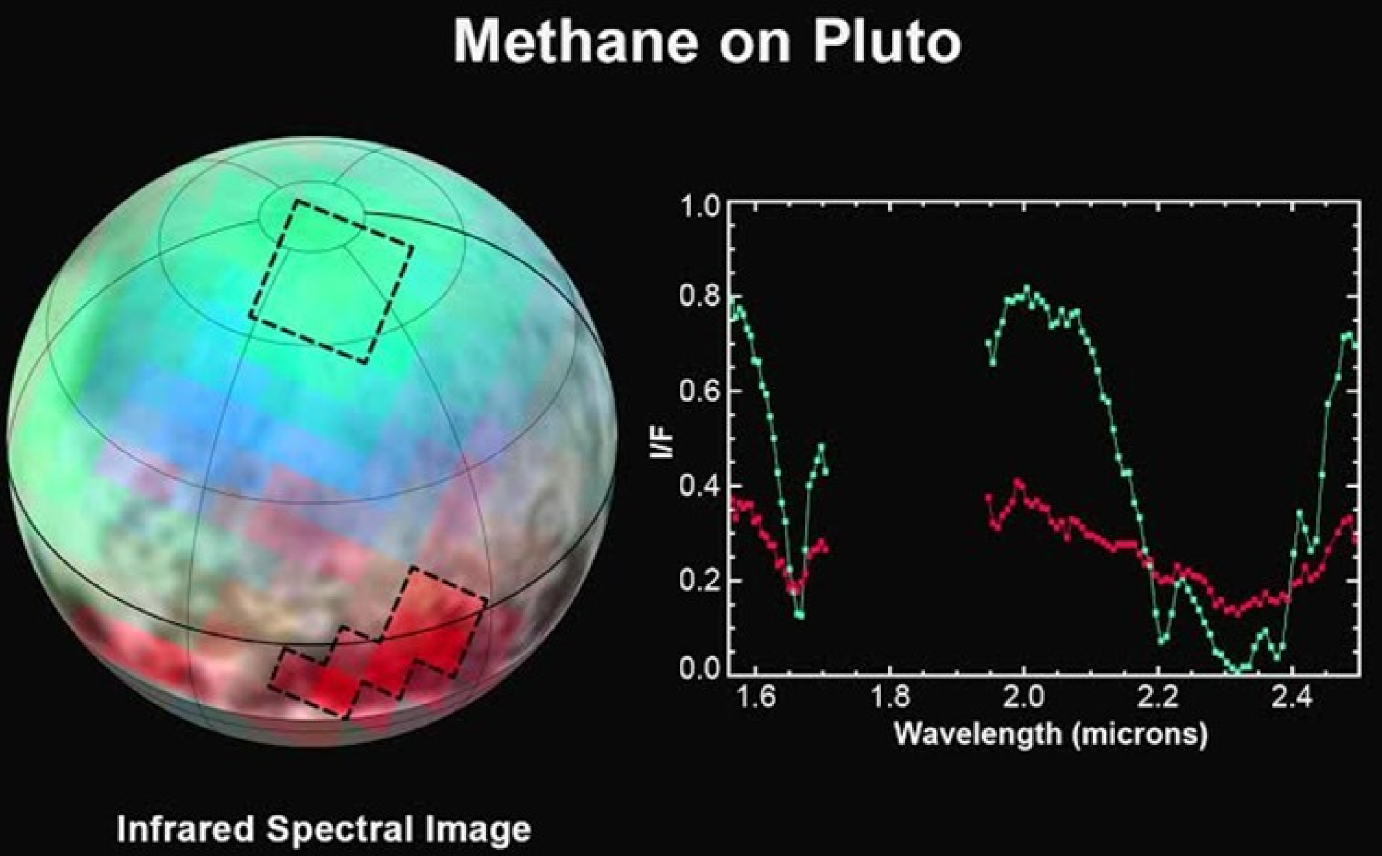


LEISA's spectral range and expected species at Pluto and Charon

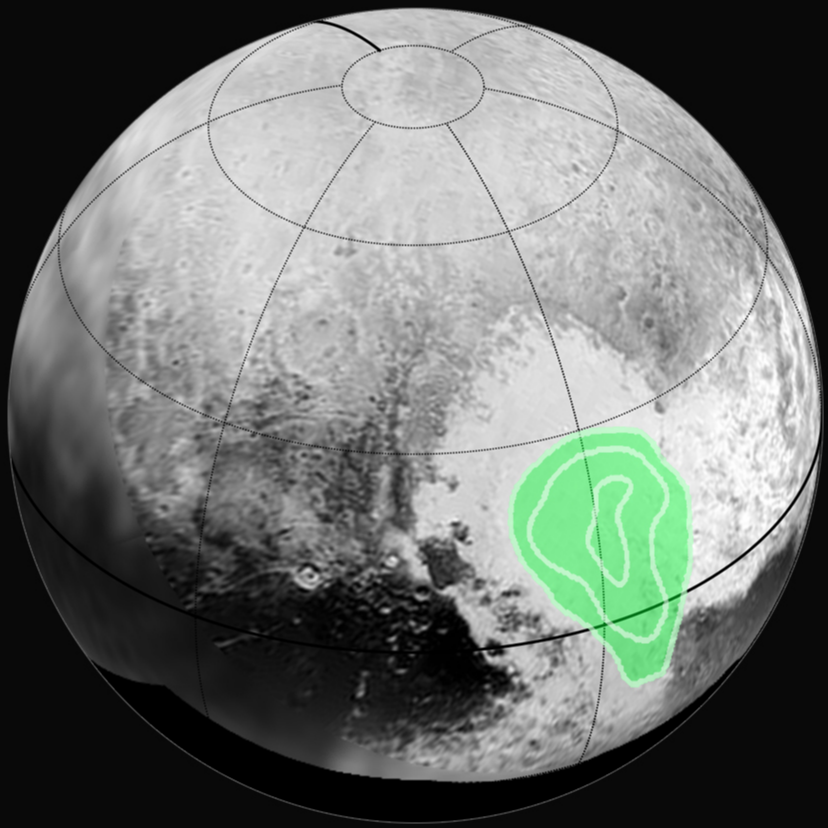


Ground-based Spectra

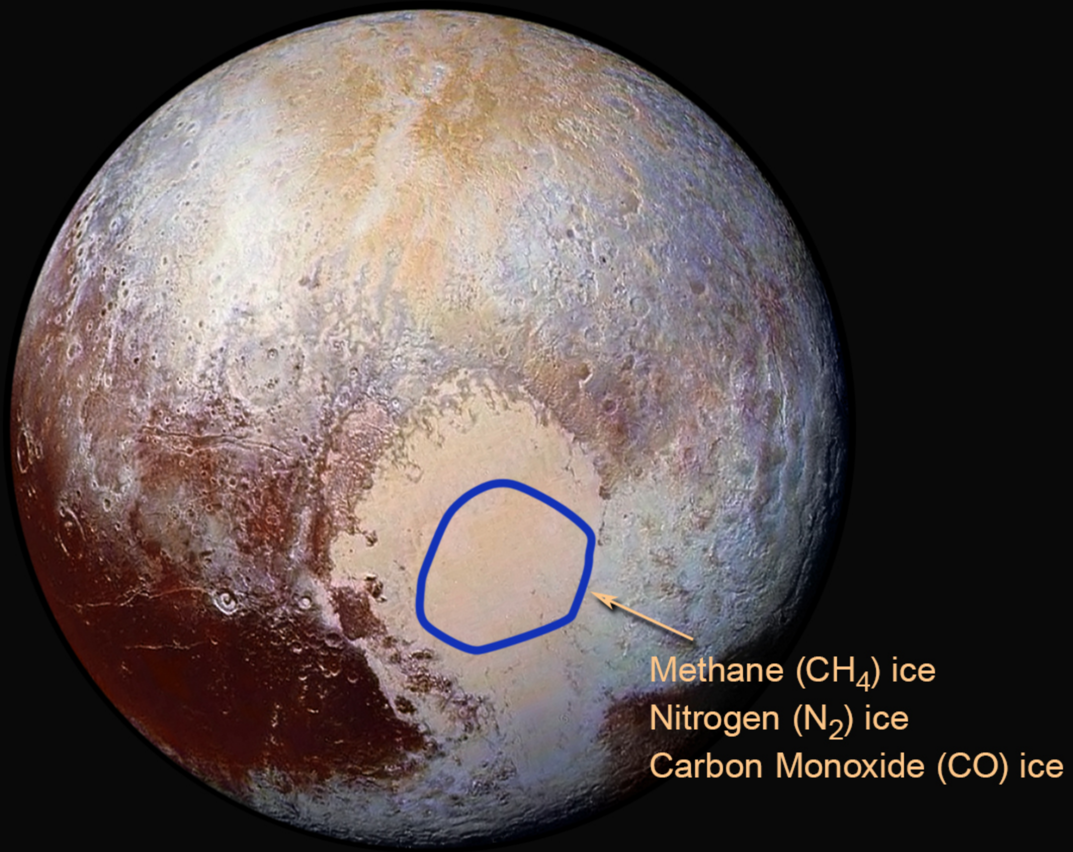
Methane Mapping of Pluto



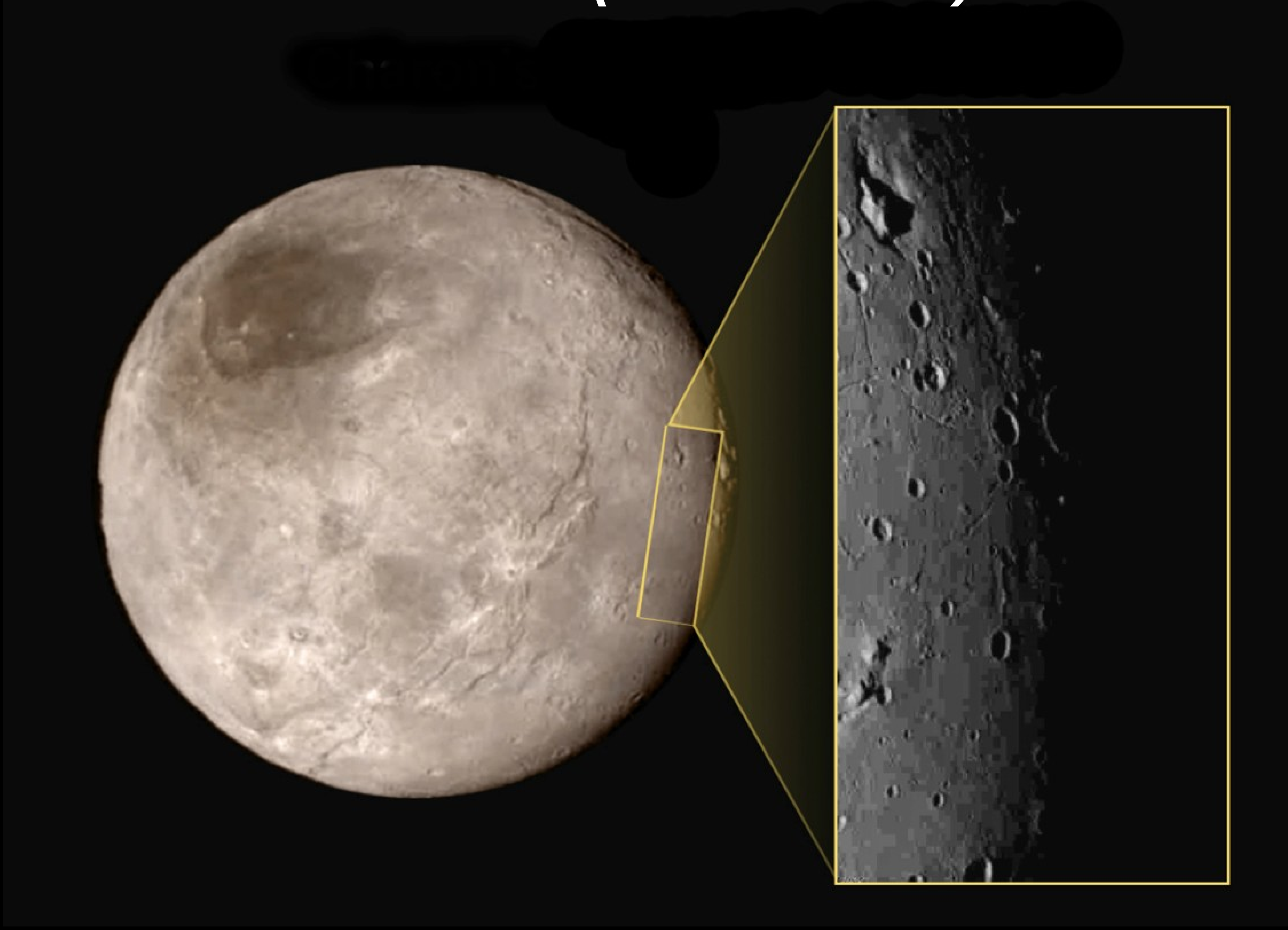
CO Ice in Tombaugh Regio



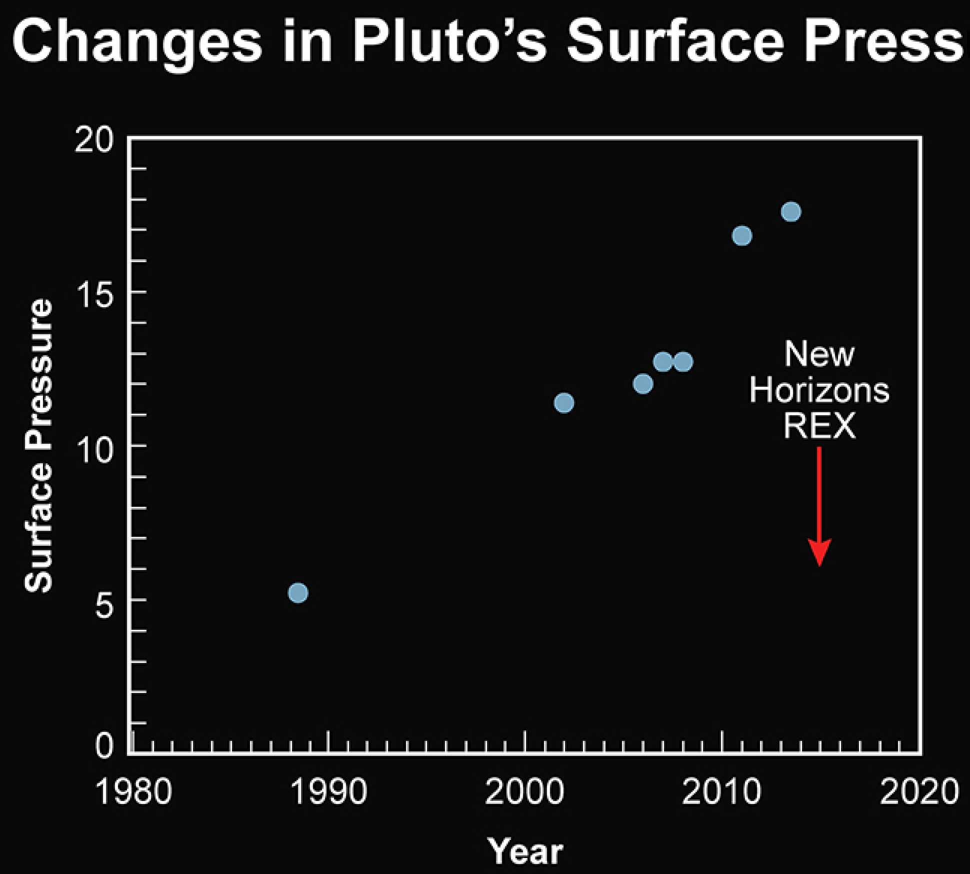
Sputnik Planum: N_2, CH_4, and CO Ices



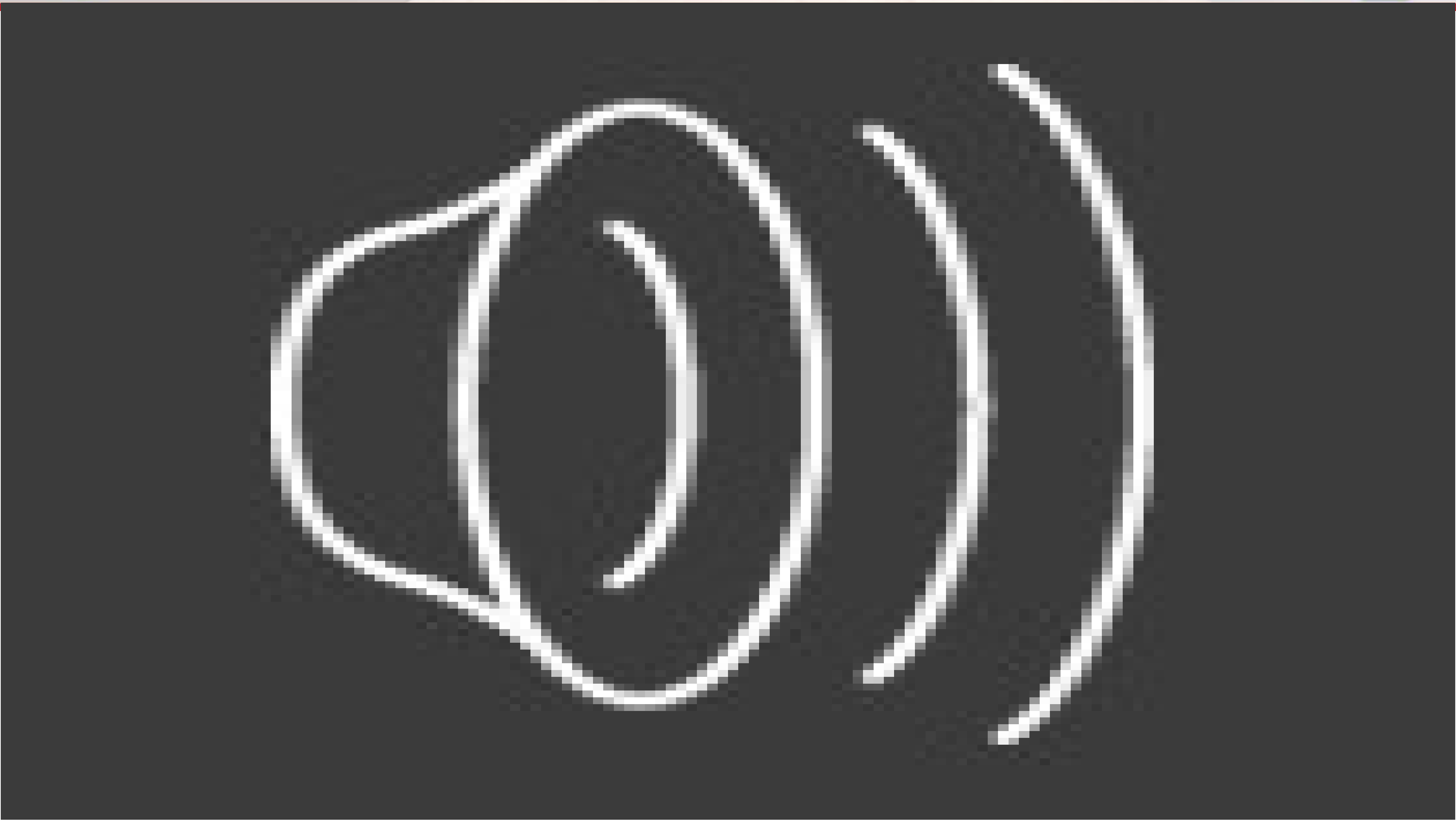
Charon After New Horizons (natural color)



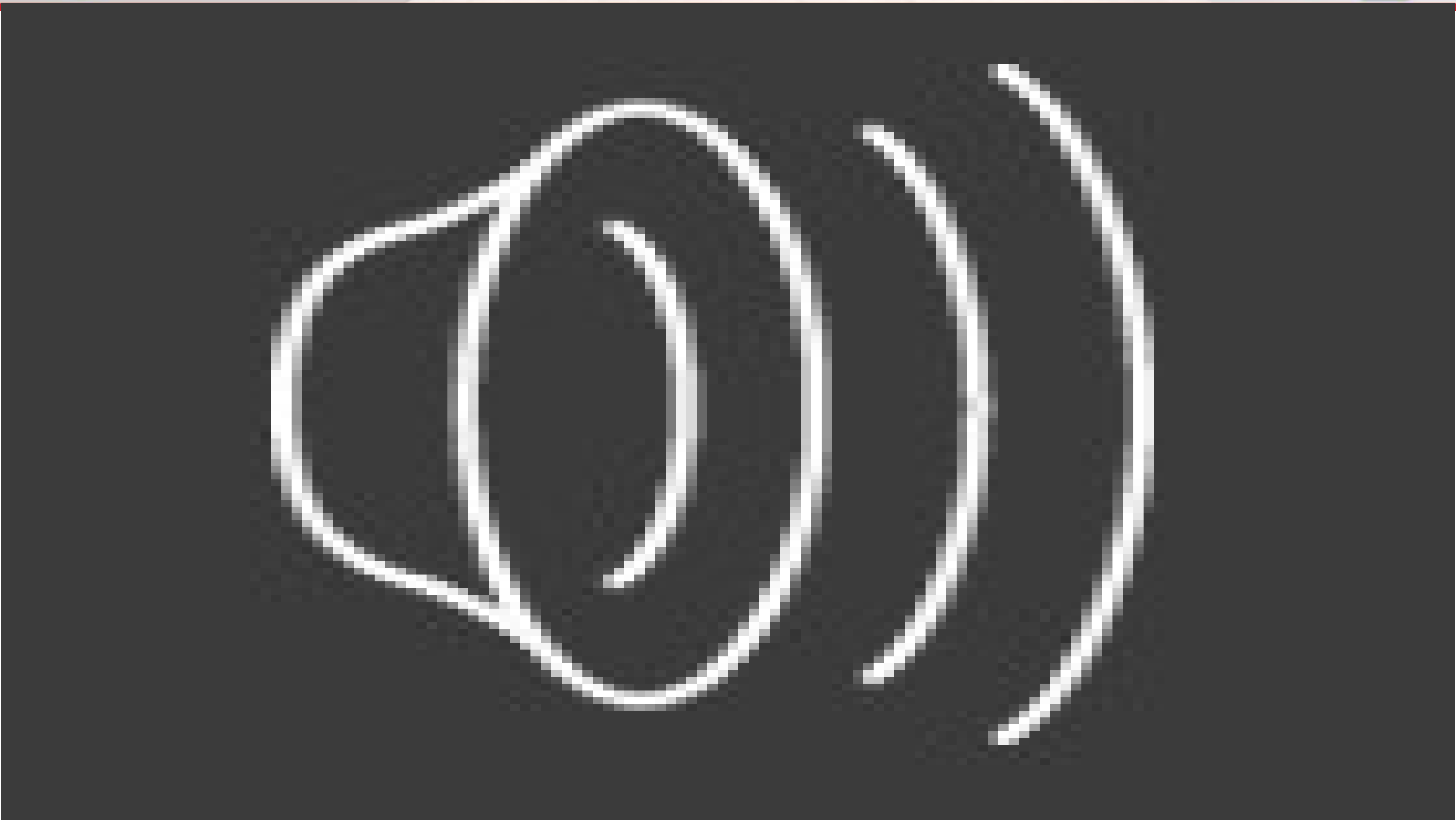
Pluto Radio Occultation (REX)



Pluto Haze Production

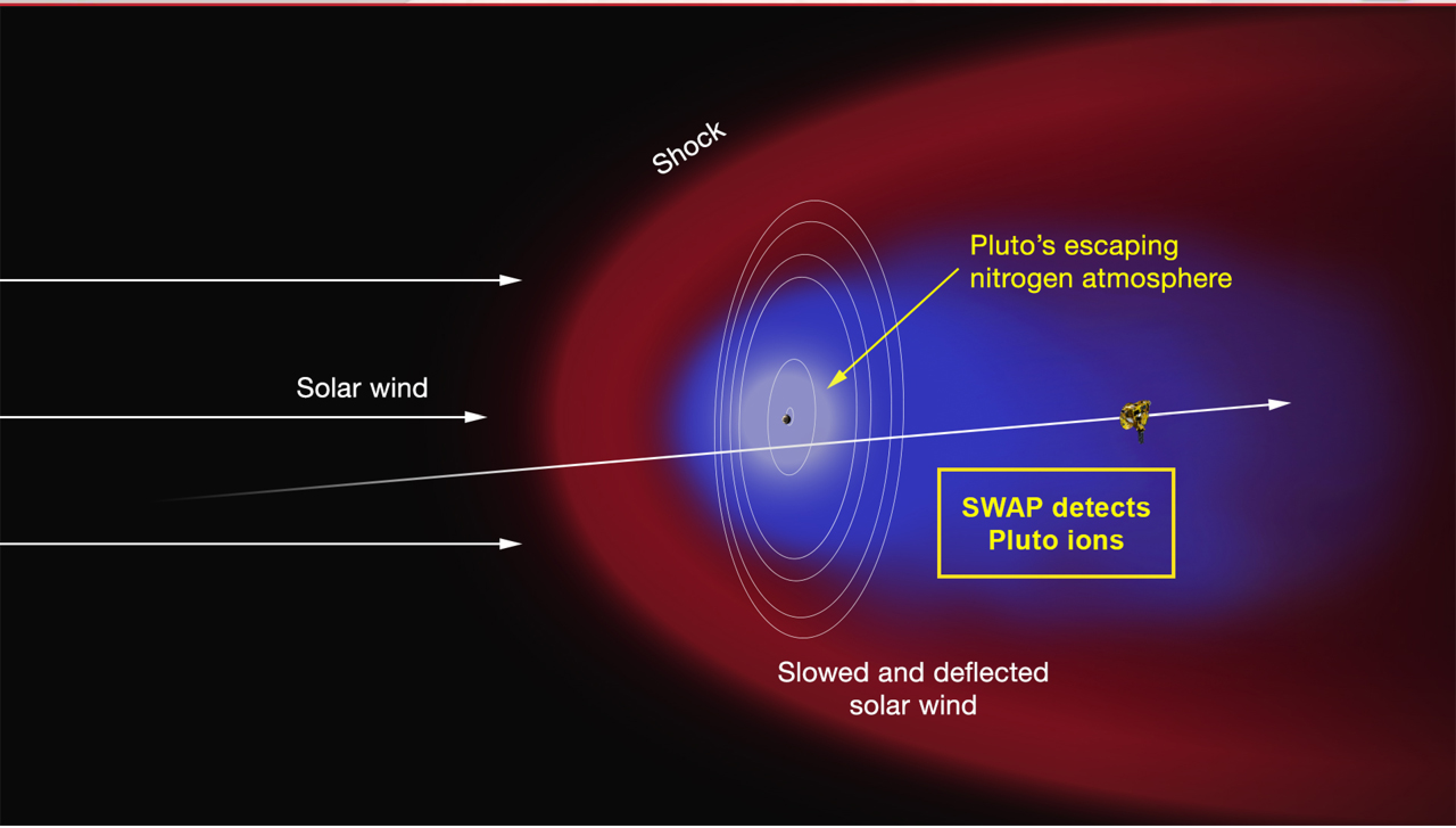


Pluto Encounter in 23 seconds



Plasma Results

Cold N_2 Plasma Detected Behind Pluto



NH Exploration of Kuiper Belt *Beyond* Pluto

- The *only chance in the next few decades* to explore more typical, primitive small KBOs

- NH *Extended Mission* will provide three different types of *unique* science:
  - Close flyby (<20,000 km) of a primitive, small KBO
  - Numerous (~20) observations of small KBOs at >5x Hubble resolution to measure binary frequency and constrain KBO formation process
  - Cruise science studying particle environment (ions and dust) in the outer solar system
    - NH plasma instruments are much improved compared to Voyager
      - Solar Wind and Heliospheric science
    - NH has Student Dust Counter (Voyager has no dust instrument)

NH Initial Results Summary

- Pluto's surface is remarkably diverse in landforms and terrain ages; wide range of albedo, color, and compositional gradients; water ice crust; ice convection and glacier flow; wind streaks
  - ***How do small planets maintain activity over billions of years?***

- Pluto's atmosphere is very extended, contains newly discovered trace hydrocarbons (C_2H_2, C_2H_4), displays a global haze layer, and has a low surface pressure (≤ 10 µbar)
  - ***Is Pluto's atmosphere starting to disappear?***

- Charon is also surprisingly diverse and shows evidence of tectonics and a heterogeneous crustal composition; no atmosphere detected yet
  - ***Can material transfer with Pluto explain dark northern cap?***

- Nix and Hydra are small, highly elongated objects covered in water ice
  - ***Higher albedo (~50%) than anticipated….Why?***

- No new moons or dust rings, despite much higher sensitivities reached
  - ***Is Pluto system dynamically saturated?***

- ***What is causing the build-up of heavy ions behind Pluto?***

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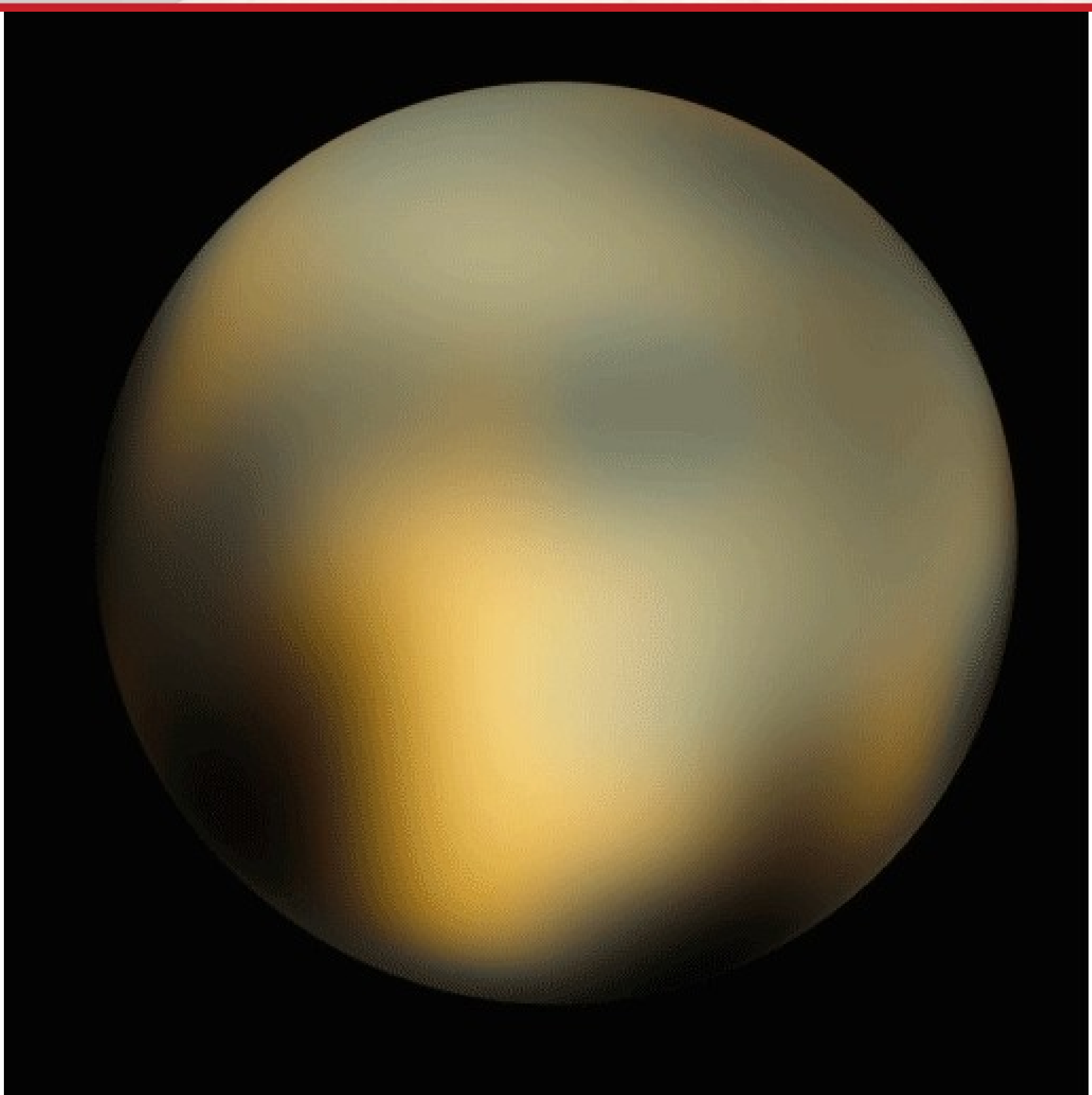
  - ***Is Pluto system dynamically saturated?***
- ***What is causing the build-up of heavy ions behind Pluto?***

Doing what has never been done before…

A Mission of Firsts

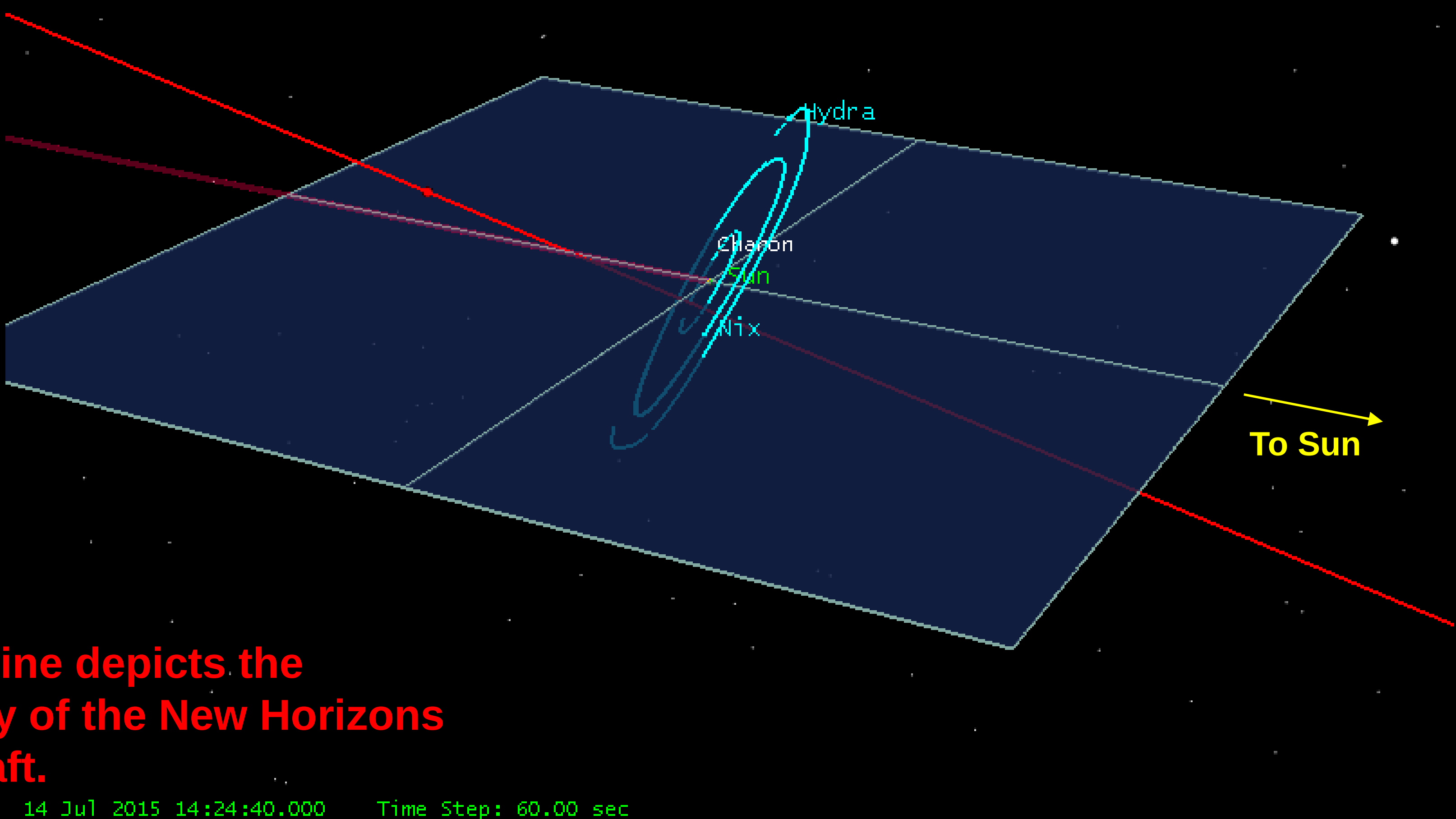
- Fastest spacecraft ever launched
- Farthest destination ever explored
- First mission to Pluto and a binary planet system
- First mission to the Kuiper Belt (The Third Zone)
- First mission in NASA's New Frontiers program
- First PI-led outer planet mission
- First planetary mission selected to carry a student experiment

But Hubble Did Pretty Well!



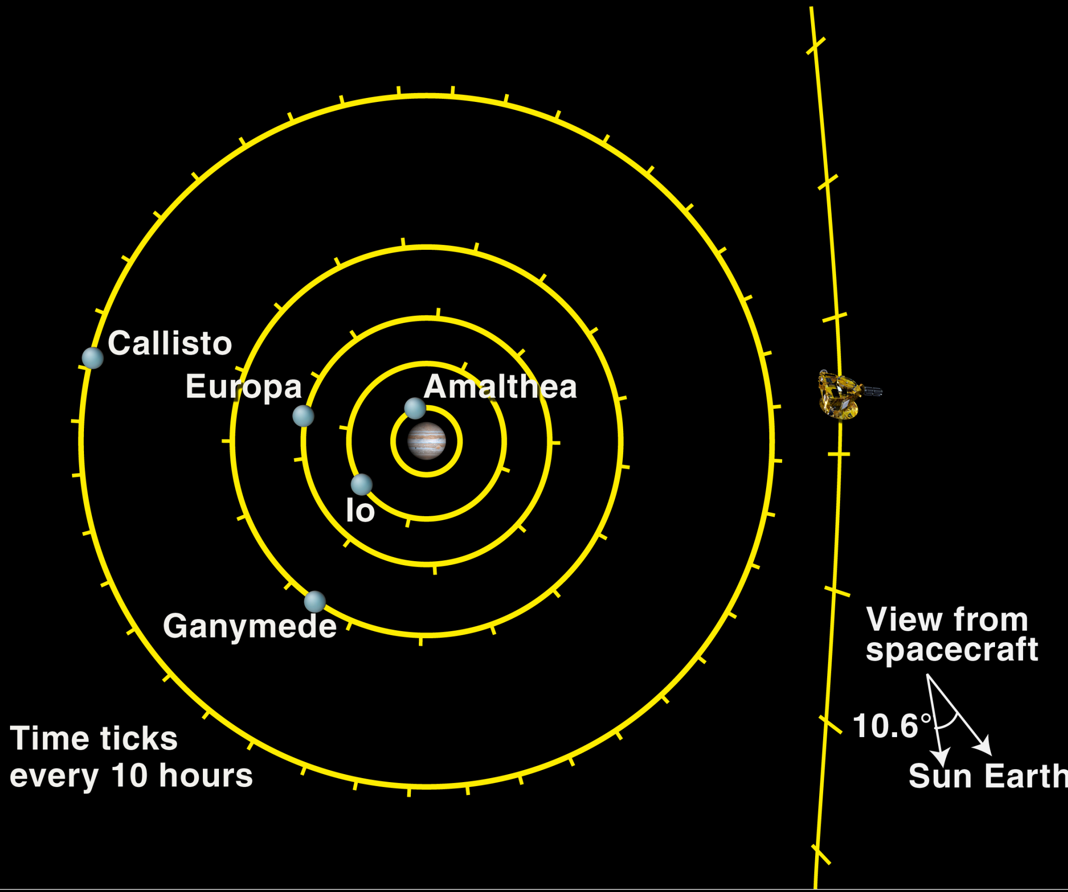
Pluto Encounter Geometry

The blue plane depicts the ecliptic.



The red line depicts the trajectory of the New Horizons spacecraft.

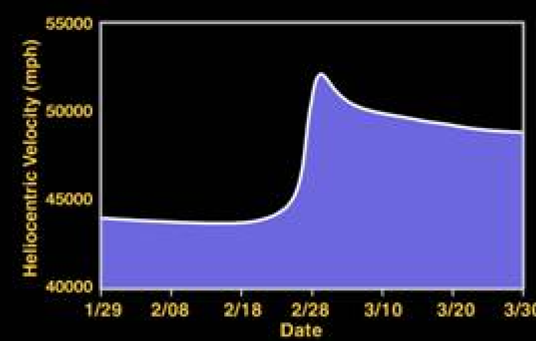
New Horizons Jupiter Encounter



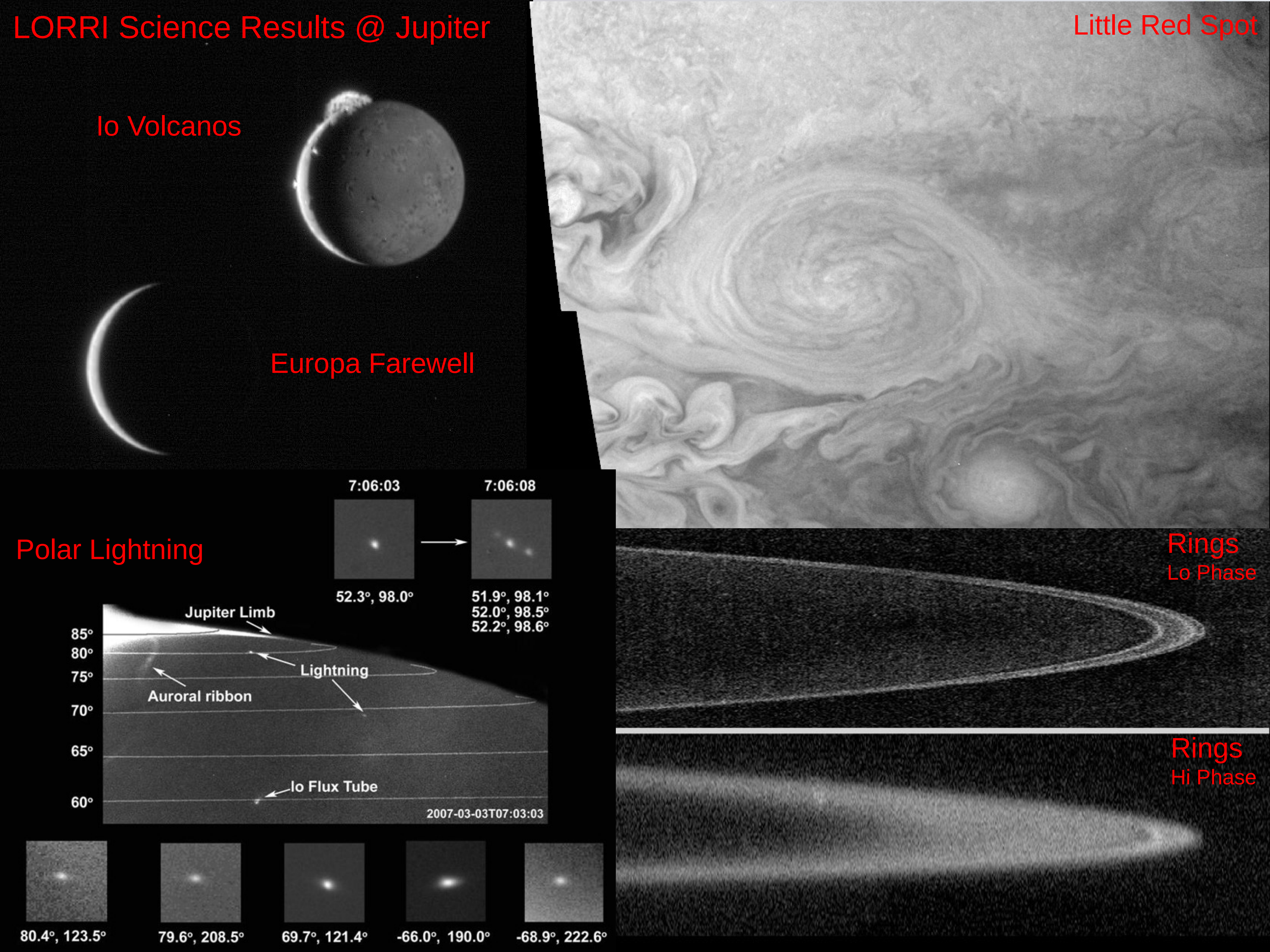
Encounter Closest Approach:
2007 Feb 28 05:43:40 UTC

At Distance of 32 R_J
2.3 million km
1.4 million miles
(1 R_J = 71,400 km)

20% Speed Boost



The main purpose of the Jupiter flyby was to get a speed boost and cut 3 yr off the travel time to Pluto, but we got some great science too.



LORRI Science Results @ Jupiter
Io Volcanos
Europa Farewell
Little Red Spot
Polar Lightning
7:06:03
7:06:08
52.3°, 98.0°
51.9°, 98.1°
52.0°, 98.5°
52.2°, 98.6°
Jupiter Limb
85°
80°
75°
70°
65°
60°
Lightning
Auroral ribbon
Io Flux Tube
2007-03-03T07:03:03
80.4°, 123.5°
79.6°, 208.5°
69.7°, 121.4°
-66.0°, 190.0°
-68.9°, 222.6°
Rings
Lo Phase
Rings
Hi Phase

- NH Flyby results published in in 2007 October 12 issue of *Science* magazine
  - Nine Papers
  - Perspective
  - Editor's Comment
  - Cover

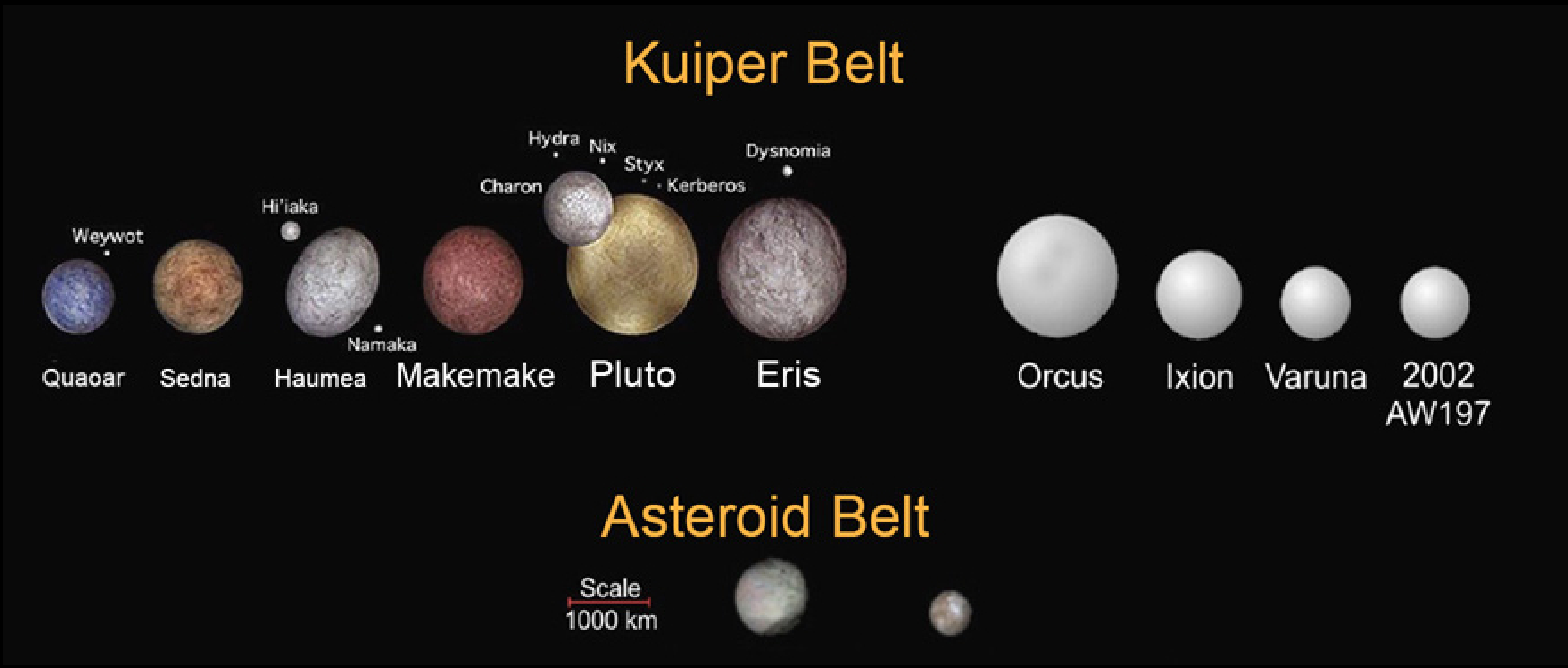
- Little Red Spot paper in Astronomical Journal (2008)

- NASA Space Science Update
- NASA press conference
- Special DPS session
- Special Fall AGU session

- NASA Jupiter Data Analysis AO released in Feb 2008
  - All NH data in PDS
  - Combine with Jovian data from other missions

Closest approach at 32 R_J on 2007 Feb 28

Dwarf Planets & Candidates

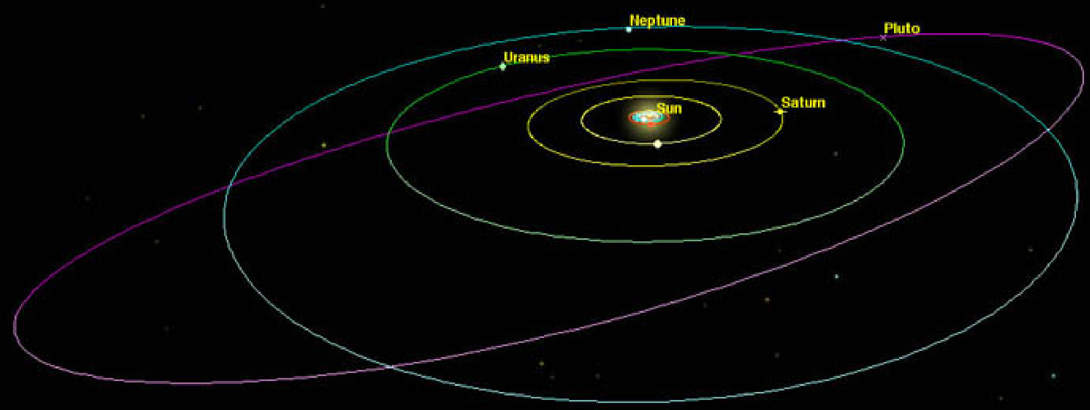


Largest known trans-Neptunian objects (TNOs)

Updated from Wikipedia

What Do We Know About Pluto?

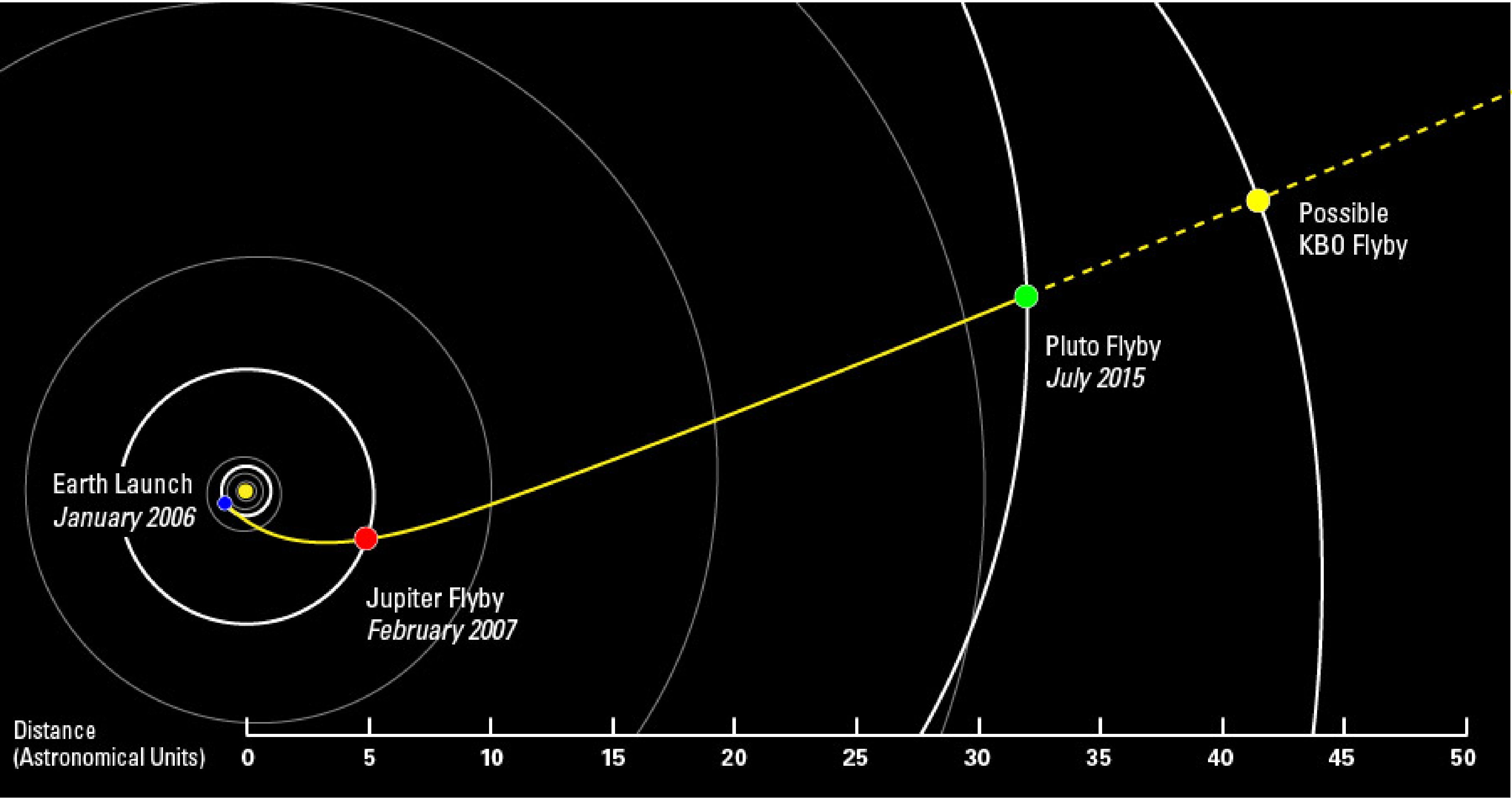
- Part of Zone 3 – the Kuiper Belt
- 1st member discovered by Clyde Tombaugh in 1930
- Later it was learned that Pluto had been imaged at least 15 times, dating back to 1909
- Oddball - orbit very unlike the rest of the classical planets



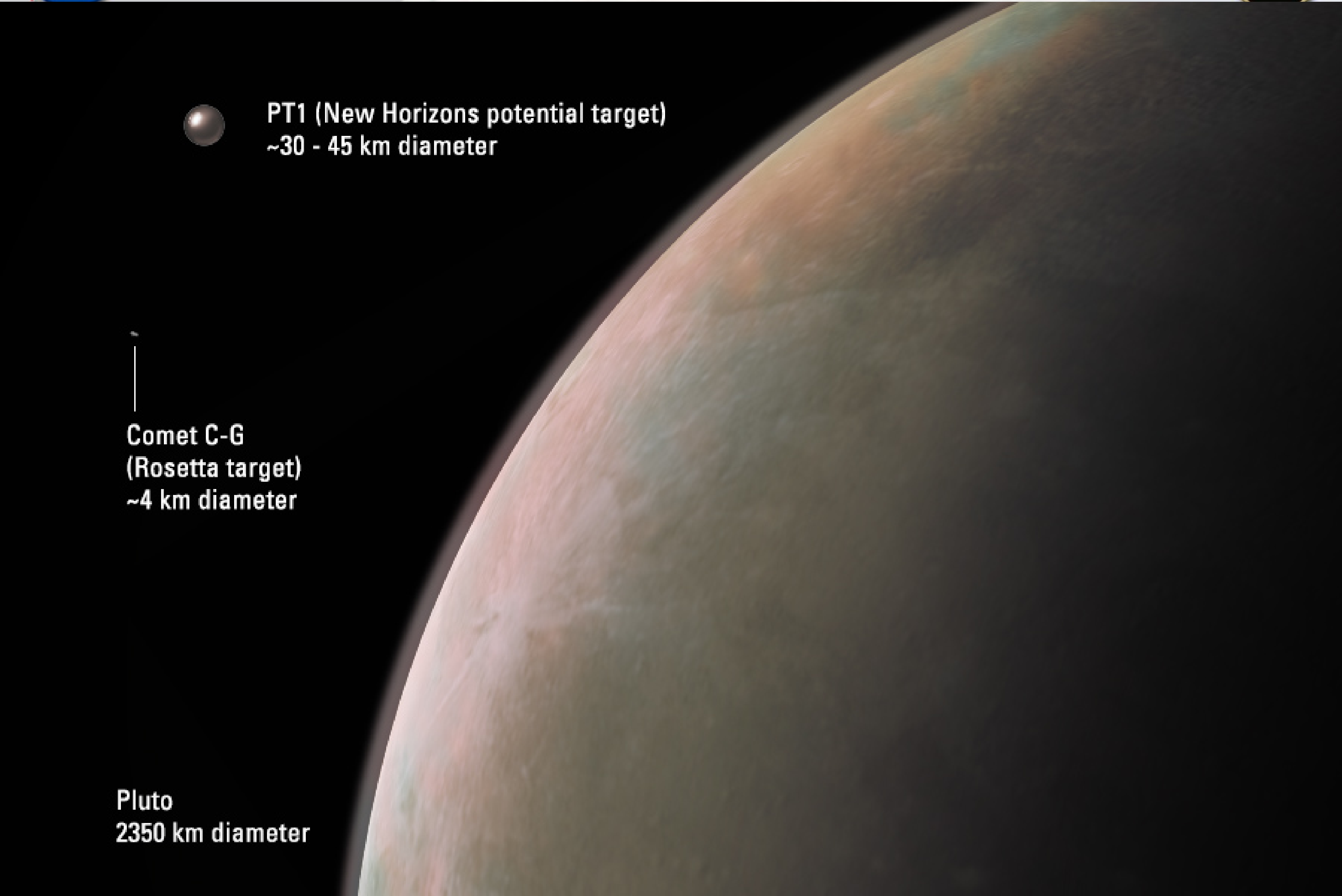
What Do We Know About Pluto?

- Pluto coined by an 11 year old girl named Venetia Burney.
- Pluto is the Roman God of the Underworld.
- Tombaugh liked the idea of ‘Pluto’ as it not only fit in with the solar system’s mythological theme, but first two letters were Perceival Lowell’s initials.

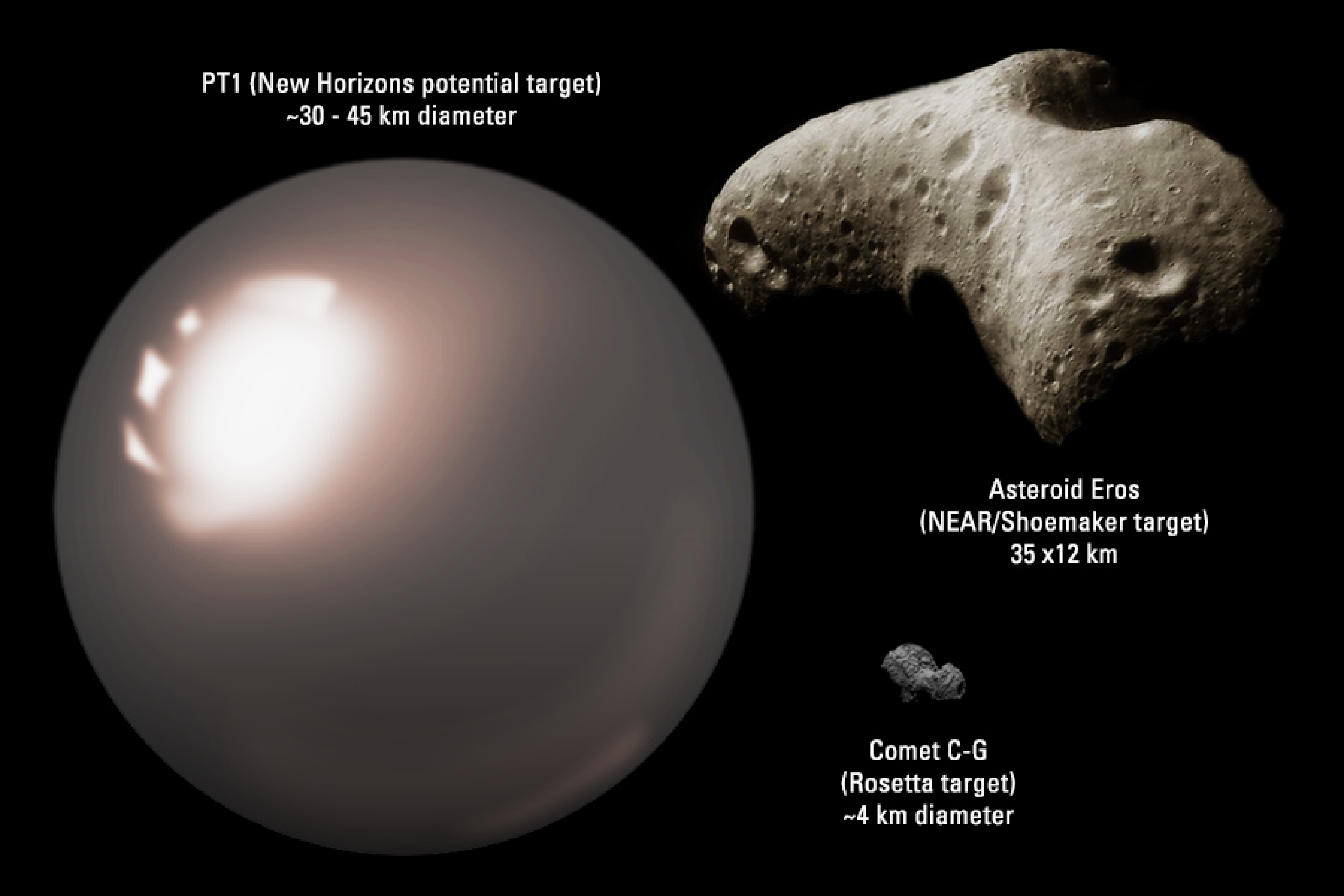
New Horizons' Path Through the Solar System



Potential New Horizons KBO Target PT1



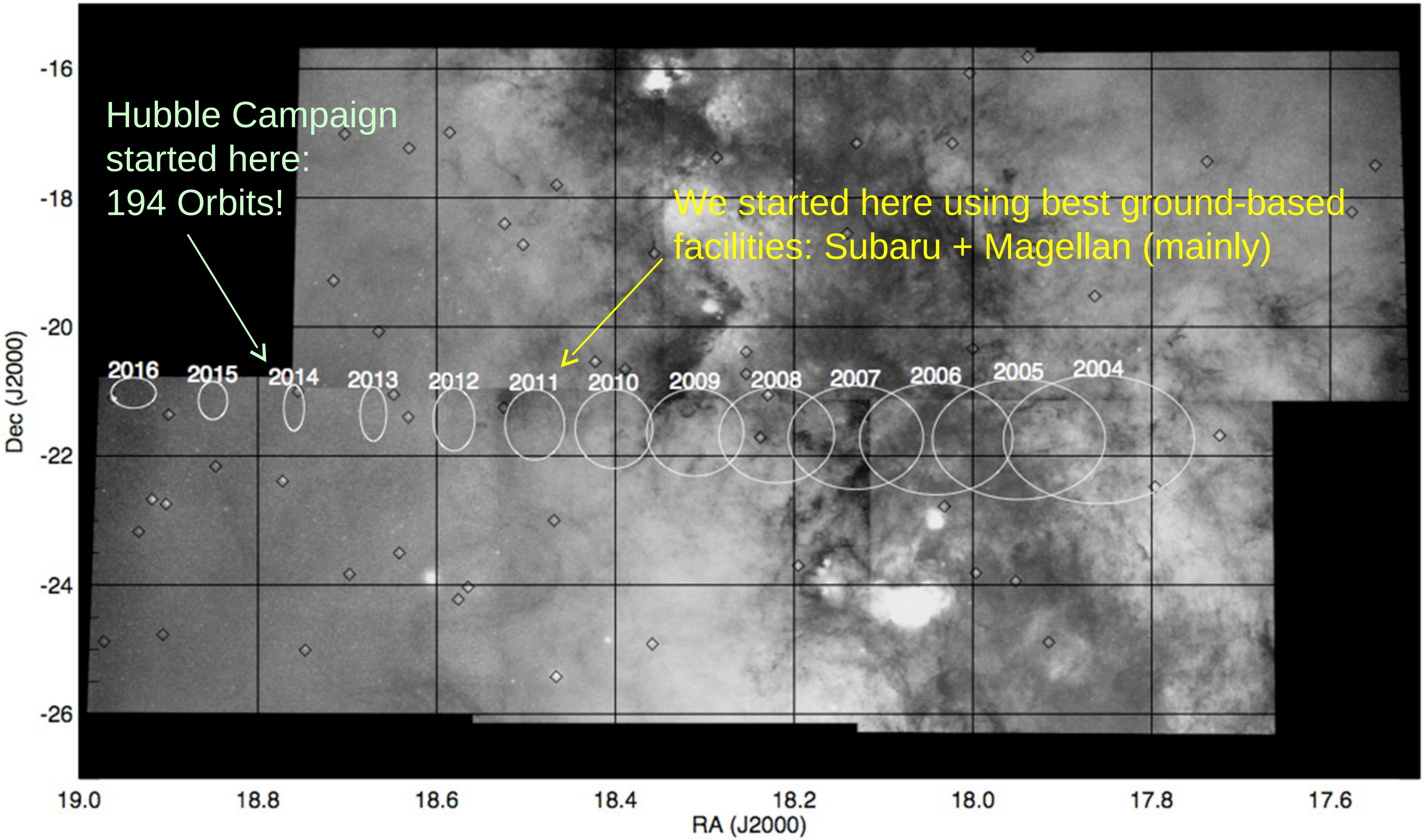
Potential New Horizons KBO Target PT1



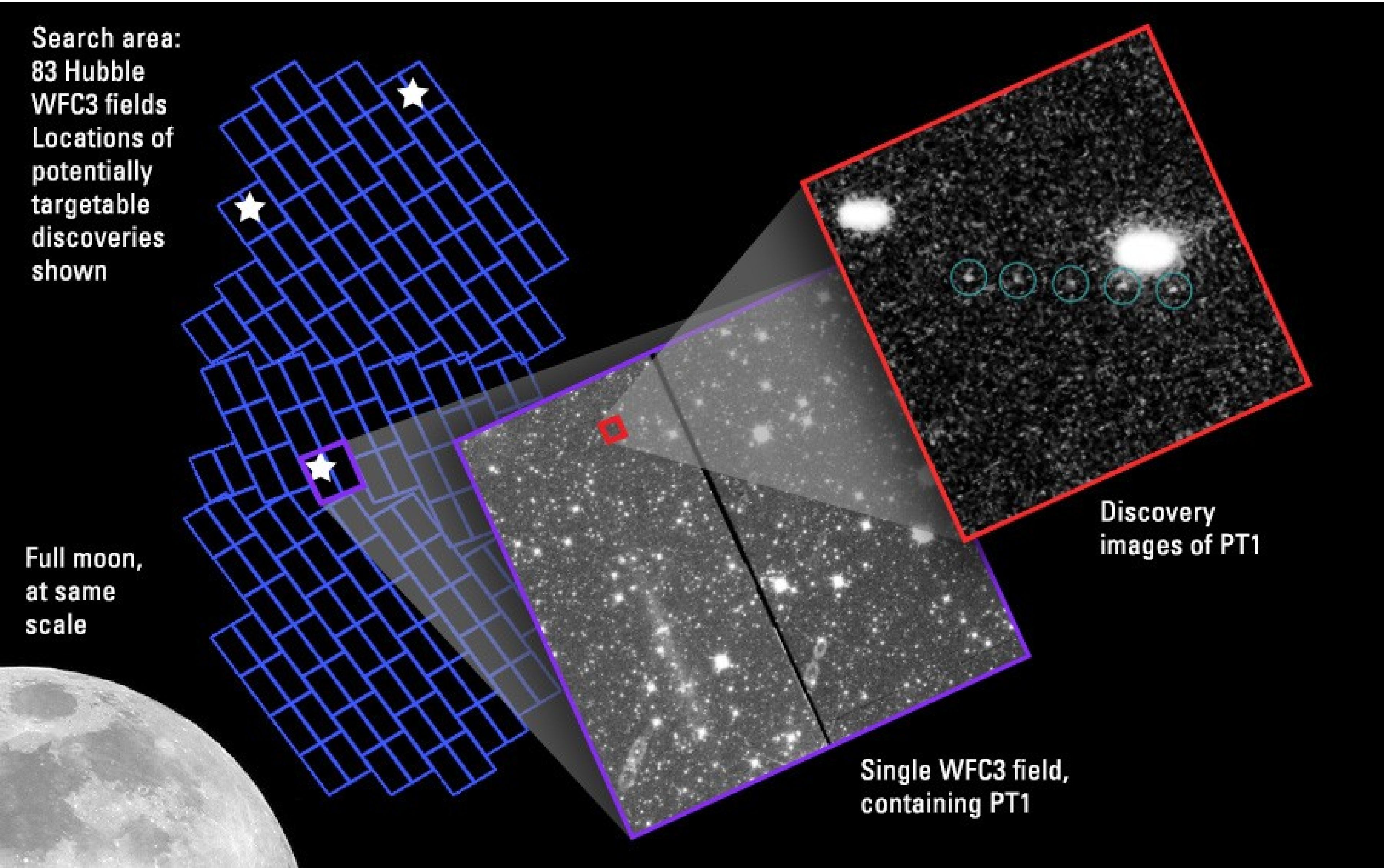
Stephen Hawking : Why New Horizons?

"We explore because we are human and we want to know"

KBO Search Region Over Time

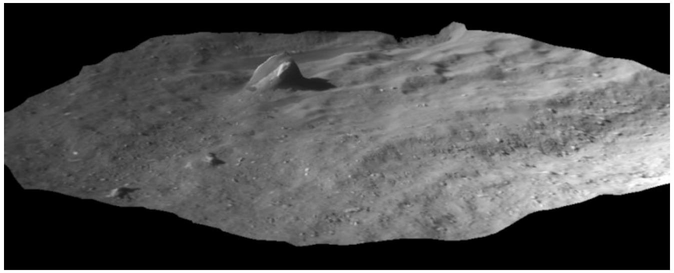


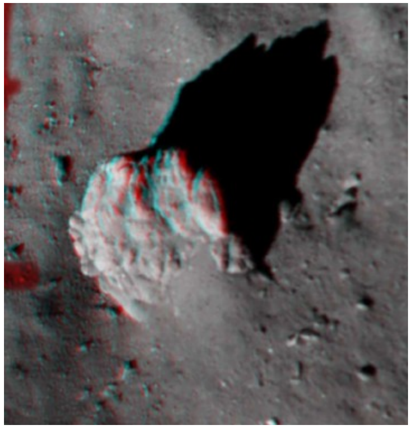
Hubble Search for NH KBOs



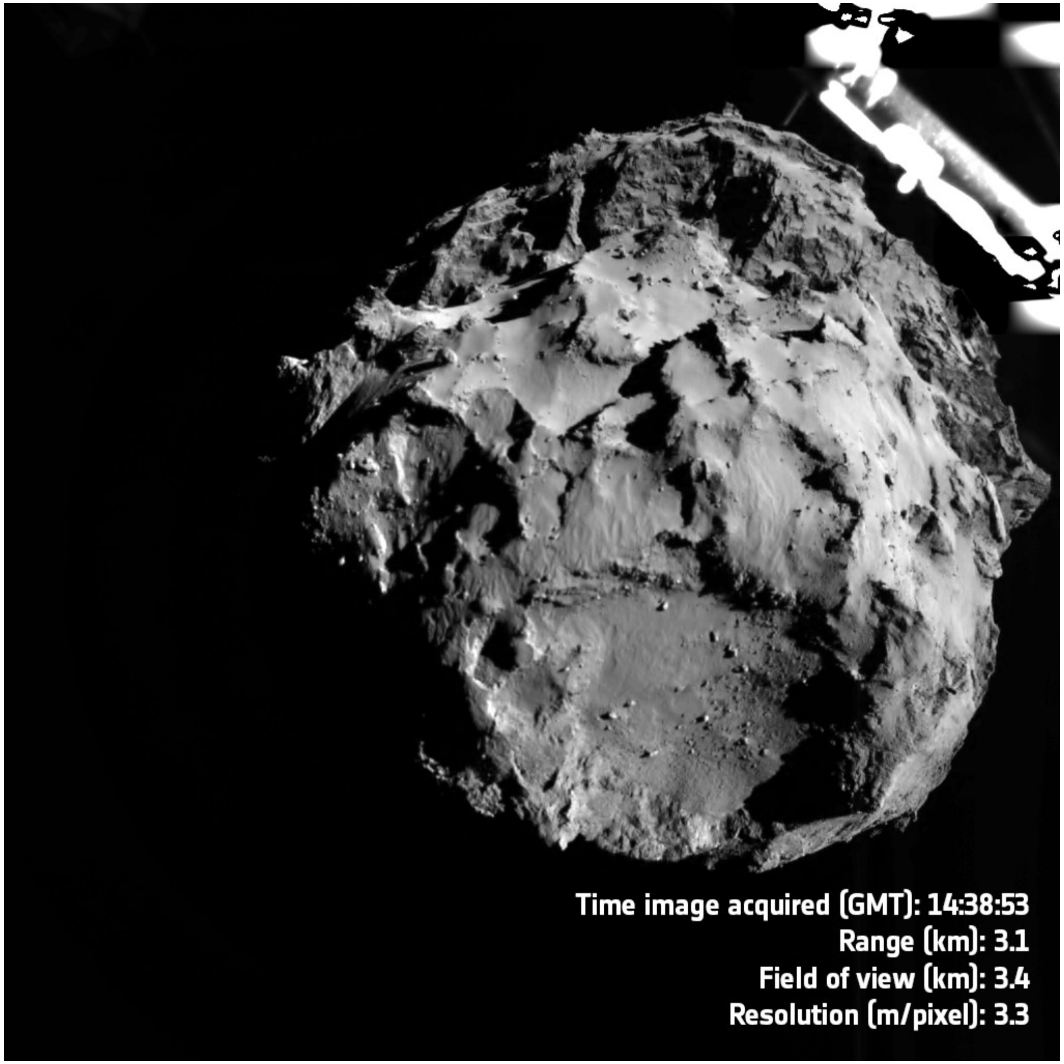
Some results from ROLIS

- Apparently coarse regolith
- „Wind tails“



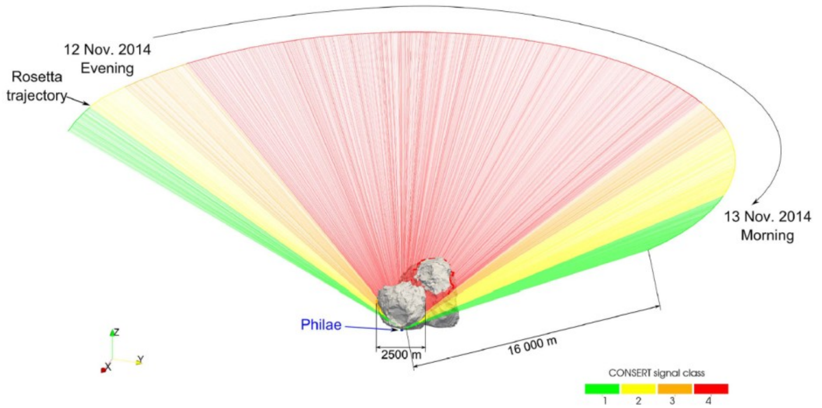


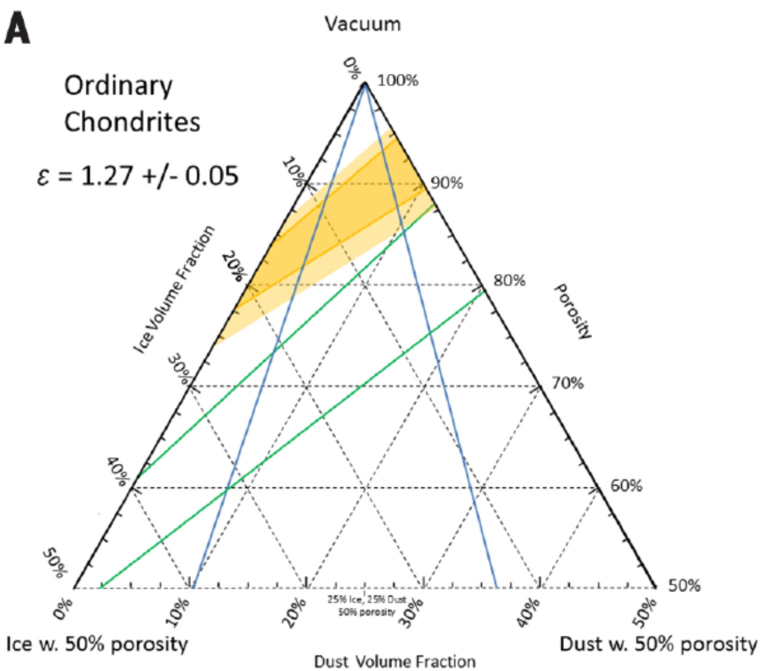
from: Mottola *et al*. Science, 2015

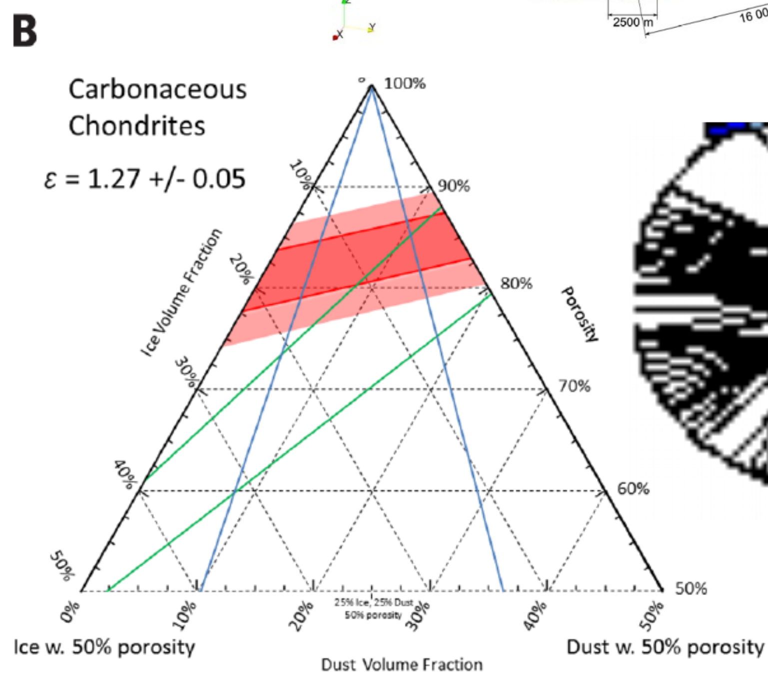


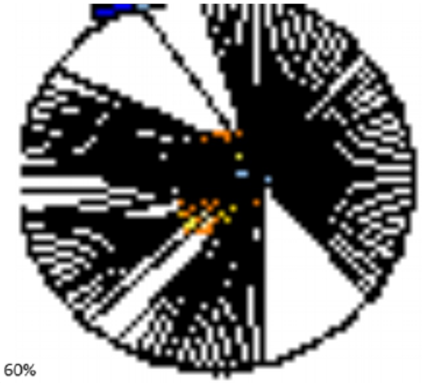
CONSERT Results

- **Average permittivity ε = 1,27**
- **Dust/ice ratio (volume) is 0,4 to 2,6**
- **Porosity is 75% to 85 %**









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